FUSION ENERGY

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRD CONGRESS

FIRST SESSION

MAY 5, 1993

[No. 38]

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HEARING SUMMARY ON FUSION ENERGY

The Subcommittee held a hearing on May 5, 1993, in Room 2318 of the Rayburn House Office Building. Subcommittee Chairman Marilyn Lloyd opened the hearing which was convened to review the current state of fusion development, to obtain a better understanding of the Administration's proposed program for the years ahead, and to receive testimony on alternative fusion processes.

Background

What is fusion research? Nationally and internationally, it is a number of scientific programs directed to the pursuit of a source of energy made possible through the joining of one or more atomic particles. Formerly called "controlled fusion" to differentiate it from atomic weapons, the U.S. Government began to research the science of deriving energy from fusion reactions around 1955. Thirty-eight years later, the effort continues. Controlled fusion has been illusive. The theory makes sense, and there is always reference to our sun, which is a fusion reactor. But the sun is a huge globe of gas in the atomic form with a central temperature of 27 million degrees Fahrenheit and a surface temperature of ten thousand degrees Fahrenheit. The density is more than 90 times that of water. At these great temperatures and densities, thermonuclear reactions convert hydrogen into helium, releasing energy which streams outward. The goal of this science program is to produce similar reactions on earth on a micro-scale. An uncontrolled version of such reactions is represented by the hydrogen bomb.

Numerous concepts have been pursued and substantial facilities constructed. Why should this science be pursued any longer? Chairman Lloyd answered this question when the hearing opened, saying, "We seek to provide a reliable source of electric power for future generations. Our oil, our natural gas and coal—remaining world resources—are all limited to a relatively short period of time."

Chairman Lloyd continued, "Columbus reached our shores about 500 years ago. In much less time than that, fossil fuels which provide for today's energy, for all practical purposes will be exhausted. Fusion promises us a virtually unlimited supply of potentially clean energy."

A number of fusion processes have been tried, however. Many facilities have been constructed. There was the "mirror" process at Lawrence Livermore. The concept included an enormous cylinder with magnets wrapped around the exterior and even more elaborate magnets at the ends of the cylinder. As in most experiments, the objective was to press isotopes of hydrogen together with sufficient force, at a high temperature for a sufficiently long time to cause them to "fuse" and release more energy than it took to provide the reaction. But ion leakage foiled the process by resulting in losses at the ends that could not be stopped.

Meanwhile, the main line scientific effort in the United States, Europe, Japan, and Russia has been primarily directed toward the "tokamak" concept. A Russian invention, the tokamak is a cylinder bent around in a circle (toroid) and the ends joined. Powerful magnets wrap around the cylinder vertically and horizontally. Inside the cylinder an ionized gas is to consist of deuterium and tritium. This ionized gas is then heated. There has been some scientific success in achieving first-order reactions, but the sought-after sustained reaction has been illusive.

Senator J. Bennett Johnston led the FY 1994 authorization when he introduced S. 656, a bill which shocked the "fusion community". The bill served to basically limit work in fusion physics to the International Thermonuclear Experimental Reactor Program (ITER). ITER is an international program with four primary participants: the European Community, Japan, Russia, and the United States. This bill served to put the fusion community "on notice" that "time was running out" in an era of tight money supply. S. 656 served to bring forth other scientists not associated with tokamak development, thereby putting more pressure on the "main line" program. The main line program, as proposed by the Administration, also includes a new facility, the Tokamak Physics Experiment (TPX), to be constructed at the Princeton Plasma Physics Laboratory.

Other potential concepts, such as Heavy Ion Inertial Fusion, and aneutronic mirror fusion science were not included in the President's FY 1994 budget. This served to limit research to one option, the tokamak.

The hearing proceeded on the basis of four major considerations: the ITER, deuterium/tritium experiments at Princeton, the TPX, and other approaches to achieving a scientific breakthrough.

Opening comments

Congressman Fawell addressed the audience, delivering comments made by Dr. Robert L. Hirsch, a well-known and respected fusion scientist and currently a Vice President of the Electric Power Research Institute (EPRI). Congressman Fawell conveyed Dr. Hirsch's primary concerns: The tokamak and laser fusion reactors as currently envisioned will be extremely complex, highly radioactive, and are likely to be highly regulated and costly (if they were to be built).[1]

While Dr. Hirsch's comments make sense, there are no known alternatives to fusion as a major long-term source of primary power sufficient to meet future industrial and residential electric power requirements.

Congressman Fawell went on to state "no DOE budget documents provide either a cost estimate, a time schedule, or an understandable rationale of why the proposed research is so important."

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[1] The Committee has not supported funding for a laser fusion device on the basis of inadequate energy density in the driver. The Committee has supported a heavy ion driver in the Energy Policy Act of 1992.

Congressman Scott noted that "we're still at least decades away from realizing any tangible benefits from our extensive efforts in developing this technology."

Congressman Schiff stated, "I think it's time we did an evaluation of our fusion research. Given (that) the dollars for research and development are getting harder to come by, we need to establish where we are and where we're going."

Congressman Swett mentioned his interest in alternative approaches to fusion stating that other researchers both here in the U.S. and around the world have continued to work in the field of alternative approaches. He commented, "My concern is that if we narrow the scope [of our research too much], we [will] exclude other opportunities and alternative fuels that may be available and not give them the opportunity to grow and develop."

Congressman Bartlett stated, "I think our country, our society in general, has been somewhat paranoid about nuclear power, and I hope that more education can change the public perception."

He continued, "I think that whether or not one makes an investment in an area, that [decision] must consider the potential for societal payoff. I am a very strong fiscal conservative, but I will tell you that in the case of fusion research, because of the enormous benefit to society—fossil fuels are not forever; in the foreseeable future, we're going to run short of oil and gas, and then we're left with coal—more difficult to use—so we must have alternative energy sources. Fusion, although difficult to obtain, is going to be enormously beneficial."

The administration's program

Dr. N. Anne Davies, Associate Director for Fusion, explained the need for continuing materials development in order to reduce residual radioactivity and increase the useful life of fusion reactor components. She said, "Considerable research lies ahead to both create and contain fusion reactions as well as extract the energy in a usable form. Whatever the configuration of the first "earthbound" fusion reactor, significant work and expense lie ahead.

The present major effort is directed toward eventually producing a sustained reaction. To this extent, experiments using deuterium and tritium are to be performed this fall in the Tokamak Fusion Test Reactor at Princeton. Short bursts of fusion are expected, which will yield data related to the dynamics of the plasma and solving the 'transport problem'." (The transport problem refers to losses that limit the plasma from continuing to burn.)

This work is a science experiment. No energy will be released. A fusion facility which could produce electricity would be equipped with many more subsystems. Subsystems to continuously feed deuterium and tritium have yet to be developed. Subsystems to make tritium through have to be developed in the future. Subsystems to capture the energy gained and provide it in a useful form also have yet to be developed. Clearly, considerable scientific achievements lie ahead, not to mention development of systems through engineering design, testing, and evaluation before fusion can be considered as an energy source.

Scientists throughout the world have long collaborated on fusion science. However, the pace of this cooperation is being accelerated through the development of the ITER. Three cocenters—one in San Diego, one in Japan, and one in Germany—are participating in the design. According to informal reports, a significant degree of conservatism is being incorporated in the design to assure meeting performance objectives. The ITER is to be the first experimental facility capable of producing a continuously burning plasma. In the interim, scientific experiments continue at facilities in San Diego, D-III-D, and Alcator C-Mod at MIT.

A newly proposed facility, the TPX experiment, is to be a tokamak having a high current drive with the capability to operate on less power input, thereby advancing closer to an eventual reactor. It would be the only experiment in the world in which to verify theories at pulse lengths up to 16 minutes.

While continuing with the development of fusion science, witness Harold Forsen stated, "It is also important to recognize that there are several additional large-scale experiments that are required before the science and engineering of fusion can really be fully evaluated. These experiments should include steady state operation, materials testing, blanket design, and engineering for power production."

Mr. Coppersmith asked about fusion waste products. Dr. Forsen explained how the materials used in constructing a fusion device become radioactive as a result of deuterium being present in the plasma and neutrons resulting from deuterium reactions. He also commented on the need for the development of new materials having "low activation" properties, meaning less likely to become radioactive. He mentioned that such materials, even when radioactive, would be at a low level of radioactivity enabling easier handling techniques.

Congressman Barton questioned prior-year investments asking, "How many billions of dollars have we spent on traditional fusion research? Do you happen to know?" Dr. Davies replied that she did not know but suggested it might be about $8 billion. Congressman Barton then asked if we were anywhere near having a working fusion reactor, one with a self-sustaining ignited plasma. Dr. Davies answered that ITER would be self-sustaining, but it would be about 2005 before it was built.

Concerns about program direction

Congressman Barton expressed his interest in the aneutronic fusion concept while questioning why the program had not been funded. He asked, "Is that purely and simply a factor of all the monies going to the traditional fusion program, or are there some real scientific questions about this alternative in the research community?"

Dr. Davies answered, "that proposal or a scaled-down proposal, we have—we issued Requests for Proposals for small experiments, setting aside a million dollars this year, next, and the following year, with the idea that we would try to put more in, depending on what proposals were and how they reviewed."

Congressman Barton went on to state, "I would hope—the Department of Energy would really seriously review this particular program (referring to aneutronic fusion, which is under development by at least two non-government organizations) because if it's half as good as the proponents make it out to be, I think it's well worth spending some research dollars to verify, because it, at least on the surface, appears just on a cursory examination, to have tremendous potential."

Congressman Coppersmith asked, "Dr. Davies, if the fusion budget does not increase, how likely is it that moving forward with the new tokamak facility would result in the eventual exclusion of research on alternative fusion concepts?"

Dr. Davies responded, "I believe we are going to have difficulty moving ahead with the tokamak concept if the fusion budget doesn't increase a little bit."

Congressman Coppersmith then questioned Dr. Harold Forsen: "Dr. Forsen, I notice you were quoted in Energy Daily as saying that about ten percent of the budget should be reserved for alternatives. Should the budget not increase in real terms, would that permit a reshuffling of priorities to do that? Is it important enough to do that? Or do you see the crowding-out happening?"

Dr. Forsen responded: "I think it is very difficult if the budget maintains the level that it is now to carry forward with the international programs and domestic programs across the board. We have a real opportunity to make continued progress with the tokamak." But, Congressman Coppersmith said, "Dr. Forsen, I notice you were quoted in Energy Daily as saying that about ten percent of the budget should be reserved for alternatives. Should the budget not increase in real terms, would that permit a reshuffling of priorities to do that?"

Dr. Forsen responded that he didn't know the number showed up in print—but he added, "part of that ten percent really ought to go making the tokamak better, too."

Most scientists believe the most probable path to fusion energy is through the deuterium/tritium reaction. It is widely believed that a helium 3 reaction is more difficult to achieve. With regard to the helium 3 cycle, Dr. Davies said, "There isn't very much of it (helium) on the earth, and it does not fuse with deuterium at the same rate as deuterium and tritium fuse. It's a couple of orders or magnitude less reactive."

Congressman Coppersmith noted $350 million was appropriated for the fusion program and he asked, "How much of that went for ITER research and development?"

Dr. Davies replied, "In this year, $52 million is going to ITER, and we're planning $64.5 million next year." He then asked, "And how much of the $340 million in the current fiscal year was spent on the tokamak research reactor development, research and development generally?"

Dr. Davies said, "Oh, it must be about $188 million."

Congressman Walker noted, "I remember coming here as a relatively new Member (17 years ago) and listening to some of these hearings and being told at that time that we were ten years away from success back in the last seventies, and the time line always seems to be ten years. Now I must admit that today we're maybe becoming a little more honest. It sounds to me more like 20 years today."

Dr. Davies responded saying, "We understand enough of the fundamental science of tokamaks to understand how to design one that will be self-sustaining.

Dr. Davies also mentioned a number of fusion concepts that had been experimented with over the years. She said, "There were ion rings, there were dense z pinches, also electrostatic confinement schemes."

Congressman Walker asked, "If we put money in for alternatives, how are you going to get the community to really respond to some of the new concepts that might, in fact, get in the way of the 20 years of experimentation that has basically gone on along a single track?"

Dr. Davies noted that investments have been made in non-tokamak concepts.

At this point, Chairman Lloyd made the following statement: "This Committee should very closely look at the guidance that we're giving you in your Department, because if we're going to say you hurry up, do this as quickly as you possibly can, we're sorry that we haven't moved on it any faster than we have—but we can't have it both ways. We can't tell you to maximize your efforts and at the same time tell you to continue to look at every technology that comes along, because I don't think you can do that. And I think that's the dilemma that we have that we want to cut back on the programs, but at the same time, we have to look at what is, in our judgment, . . . the best technology, the best way to spend our money to maximize our return in the quickest possible time."

The ITER Program

According to Paul-Henri Rebut, Director of the ITER, the world is now within a factor of five of the performance required for a fusion reactor. He noted the Joint European Torus (JET) had produced a megawatt of fusion power for more than two seconds. This he said has effectively demonstrated scientific feasibility. The ITER will be the first experimental reactor and is expected to produce over a billion watts. Director Rebut commented on his interest in seeing ITER built, but his paramount objective was in seeing fusion as a major source of energy. He also sees a need for a complimentary program including an intense neutron source for materials testing, but he also believes innovation and development of a different fusion source and education and training of the next generation of scientists and engineers is important.

There has been strong support from the international team leading toward a common goal.

Director Rebut commented on the need for strong participation and leadership by the U.S.

Dr. Charles Baker is the U.S. Home Team Leader. Home Team refers to one of the four equal parties engaged in the design of the ITER; Euratom, Japan, Russia, and the United States. Dr. Baker reported the project as progressing well and noted the ITER is essentially an "engineering test reactor." The U.S. plans to spend approximately $450 million on the design of the ITER along with approximately $1.3 billion from the other three parties.

A number of U.S. companies are involved, including Ebasco, General Atomics, General Dynamics, Grumman, McDonnell Douglas, Pittsburgh Des Moines, Rockwell International, and Westinghouse. This year, activities will include engineering studies, systems evaluation and technology development. These have been funded at $52 million for the U.S. Home Team.

Dr. Baker emphasized the importance of selecting a U.S. site as a possible location for the construction of the ITER. He cautioned that such a site should be selected within two or three years. Dr. Baker also urged that site selection be expedited, especially since the design of the ITER must accommodate local terrain, soil characteristics, and communication constraints.

Continuing research at the TFTR

Chairman Lloyd questioned Dr. Baker on the definition of specific ITER design tasks assigned to the U.S. Home Team. Dr. Baker cited design of the superconducting magnets. But as he later slated, all four parties are working on the magnets.

The fabrication of superconducting wire will be shared between the parties. Chairman Lloyd then asked Dr. Rebut what ITER will accomplish that JET and TFTR will not. Dr. Rebut said ITER will provide for a self burning plasma without auxiliary heat input as required by JET and TFTR.

Congressman Scott asked about the ITER site and infrastructure requirements. Dr. Baker answered in the affirmative mentioning the need for schooling, employment for wives, the need to attract scientists and engineers. He continued saying, "what we hope to do is have the Department of Energy undertake a process to lay out how we would go about site selection in the United States.

Congressman Scott asked Dr. Rebut about the participation of industry. Dr. Rebut answered by saying industry participation was needed to advance technology development and also in producing equipment.

Dr. Baker offered that ITER was a multi-billion dollar construction project. It would offer opportunities for architect-engineers. He also cited R&D opportunities particularly in advanced materials.

Congressman Scott asked if the R&D opportunities would go to U.S. firms, to which the reply was that the $450 million in FY 94 was for U.S. R&D.

Dr. Davidson commented on the work to be done at the Princeton Plasma Physics Laboratory using the Tokamak Fusion Test Reactor (TFTR). It is interesting to note that the TFTR was once thought of as a reactor while that definition is now reserved for the ITER, the first fusion reactor.

The construction of TFTR began in 1976 and one goal was to produce fusion plasma temperatures of 100 million degrees as is required in the ITER. TFTR has passed this goal with temperatures of 400 million degrees.

The plan is to introduce tritium in the TFTR for the first time in the Fall of 1993 and produce 5 million watts of fusion power. In 1994 the power level is to be increased to 10 million watts which would be about 5 times that produced in the Joint European Torus in 1991.

Environmental safety and health compliance requirements have been proceeding well including approval of the environmental assessment (EA), public briefings and DOE approval of the final safety analysis report. The Energy Policy Act of 1992 also calls for the design and construction of a major new national facility for fusion R&D. The facility, called the Tokamak Physics Experiment (TPX) is also to be constructed at the Princeton Plasma Physics Laboratory.

It is hoped that results from the TPX will eventually contribute to a smaller, more economical fusion reactor that could operate continuously. The TPX is to use some of the existing facilities at Princeton. Design of the TPX is scheduled to begin in Fiscal Year 1994.

Chairman Lloyd asked if the TPX would be completed in time to have an impact on the ITER.

Dr. Davidson responded saying he thought it would impact ITER in several ways. First, he said through superconducting magnet design, and accommodation of higher power densities, through testing advanced diverter concepts and through design of high heat flux components.

Congressman Fawell questioned Dr. Rebut about materials problems and Dr. Hirsch's comments about there being no qualified materials. Dr. Rebut answered by differentiating between "First Wall" (the neutron shield) and the reactor structure. He said the first wall materials will need to be replaced depending on the amount of destruction by the neutrons, and he mentioned the search for low activation materials. He also mentioned the possibility of recycling such materials.

Congressman Fawell asked Dr. Baker if he saw a need to rebuild a fusion reactor every five or ten years. Dr. Baker indicated no, that only the first wall, constituting 10 percent of the reactor would have to be replaced.

Mr. Fawell then asked about the Deuterium-Tritium (D/T) experiments at Princeton and how they would impact decommissioning and decontamination of the TFTR. Dr. Baker replied that it would take a year for the TFTR before it would be ready to decommission and the decommissioning would take two to three years.

Mr. Fawell went on to ask what would be learned from the D/T experiments. Dr. Baker responded they would explore the effects of D/T plasma on equilibrium, stability and the transport process. He also expects to see initial evidence of alpha particles producing some self-heating of the plasma. These experiments will be important in supporting ITER in its ignited plasma stage. (That is in design and construction for ignited plasma.)

Alternative energy concepts

Congressman Swett chaired the part of the hearing which covered alternative fusion concepts. The first witness was Dr. Klaus Berkner, Associate Laboratory Director of Operations at Lawrence Berkeley Laboratory. Dr. Berkner addressed the Heavy Ion Fusion Development Program. He explained the relationship to the defense program and mentioned substantial progress in the last two years. In deference to a Tokamak, the Heavy Ion program uses an accelerator to strike tiny pellets with beams having a hundred trillion watts of power forcing the pellets, which contain deuterium and tritium, to implode and force the deuterium/tritium to fuse, thereby releasing energy.

The heavy ion beams require further development for energy systems. The next step in this program is the development of the Induction Linac System ILSE which was also included in the Energy Policy Act of 1992. The conceptual design has been completed and the cost for development is estimated at $4 million and three and a half years to complete. The ILSE has been talked about for five years.

Dr. Berkner stated the Fusion Policy Advisory Committee, in 1990, recommended heavy ions as the proper driver for development of commercial inertial fusion energy.

The National Academy of Science also endorsed the ILSE program, and recently, the Fusion Energy Advisory Committee also endorsed the development of the ILSE.

Dr. Berkener testified that progress in heavy ion fusion research has been successful technically, but has not been adequately funded.

When this program was transferred to the Office of Fusion Energy it was funded at $9 million in 1992. It dwindled to $8 million in 1993 and $4 million in FY 1994. This level of funding is unrealistic. $20 million per year is needed to develop the Heavy Ion inertial fusion system.

Aneutronic fusion was presented by Dr. Bogdan Maglich, Chief Scientist for the Advanced Physics Corporation. Dr. Maglich mentioned that the General Electric Corporation is also involved in researching this technology. The Committee also recognizes that several other scientists are pursuing the same technology.

Dr. Maglich mentioned the use of lithium in tokamaks (which is needed to breed tritium) saying, "They (meaning tokamak scientists) need two fuels that are often ommitted (not discussed). They are highly toxic beryllium, and highly flammable lithium, enormous complexity-wise, and because of the low power density, very expensive per unit of electricity to get generated."

Dr. Maglich continued, "First the size of the fusion reactor, for the past 30 years there has been a tenet that fusion reactors must be large. The larger it can be made, the more likely that it will work. That is why the only power—generating—this is the only power generator in the world whose nonoperating model would cost $10 billion. This is leading to the escalation of money and size of proportions that has completely damaged any chance of getting financial funding for this type of fusion."

Dr. Maglich proposed that a new office be established in the Department of Energy, under entirely new management, which would provide for the development of alternative technologies leading to the generation of electric power from the fusion of light elements. He also stressed the need for industry participation in such developments.

Dr. Edmond Storms acting in his own behalf presented testimony on a non-tokamak approach to producing energy from certain elements. He stated: "Starting with the work in 1989 by Drs. Pons and Fleischmann, many observations have indicated that it is apparently possible to initiate nuclear reactions in certain metals near room temperature and that these reactions result in significant heat production as well as various low-level nuclear products."

He continued, "Much skepticism and frustration resulted from lack of reproducibility during early experiments. For this and other reasons, many scientists still believe that positive results are not possible. However, the phenomenon is now reproducible using a variety of techniques. Excess heat production has occasionally approached useful levels, and many positive results are now described in a variety of peer review scientific journals and conference proceedings."

In fact, the information, the evidence is now so persuasive that it has caused the Electric Power Research Institute, EPRI, to support the work at $4 million a year at SRI and Texas A&M University, where positive results have become increasingly reproducible."

"A company called Technova in Japan is sufficiently impressed by the evidence to equip a large laboratory in France for the use of Drs. Pons and Fleischmann. They can now produce power densities that are ten times those produced by a nuclear power reactor. This means that the rarity of palladium is no longer a problem and that such reactors, sources of heat, will be relatively compact."

"Support is especially strong in Japan, where MITI has recently committed $24 million to be added to other sources of funding. Indeed Japan is now leading the field in understanding this remarkable phenomena."

Dr. Storms continued, "The phenomena will eventually be understood and useful devices will be constructed."

Finally, Dr. Storms stated, "The U.S. Patent Office is not issuing patents in this field while this limitation does not exist in other countries."

Congressman Swett asked the witnesses to state the funding necessary to "move their science off the dime and into an active mode toward accomplishment." He then proceeded with Dr. Berkner who answered, "In the heavy ion fusion programs, the Fiscal Year 1993 budget is about $8 million. The line that's in for 1994 is $4 million. To do the program, that the fusion Energy Advisory Committee recently recommended is a $20 million per year effort."

Dr. Maglich answered: "Yes, but actually, we have requested from DOE only $17 million. The balance would come from industry." Dr. Storms responded: "Well, in our case the contribution from the government, the official contribution from the government or the DOE are zero. And so any bit would be a very—would have a big impact. Contributions from outside sources—industry, EPRI, and whatever—are probably in the neighborhood between $5 and $6 million. So I would suggest something in the neighborhood of $10 million would be a significant improvement in the present situation and have a big impact without having a serious impact on other programs."

Dr. Mills answered: "I've been solicited by a number of national labs and academic institutions who would like to work on this. Dr. Mills continued saying that, so far it has been all private funding and that he was within 95 percent of having the theory, the product, the reaction, and an incontrovertible heat demonstration device done with their own funds."

Congressman Swett also questioned the time it would take to bring the various technologies to commercial viability. Dr. Mills said 5 years, but Dr. Storms mentioned legal and environmental considerations that would have to be resolved and did not speculate on a specific time period.

Dr. Maglich said $30 million over 3 years for a 1 kilowatt plant, and $1.5 billion over 5 years for a 33 kilowatt commercial plant.

FUSION ENERGY

WEDNESDAY, MAY 5, 1993

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 1:35 p.m., in room 2318, Rayburn House Office Building, Hon. Marilyn Lloyd (Chairperson of the Subcommittee) presiding.

Mrs. LLOYD. Good afternoon, ladies and gentlemen, and the Subcommittee will come to order.

I would ask unanimous consent that today's proceedings be covered by the media. Without objection, so ordered.

Today we will receive testimony from witnesses in the fusion energy field. The United States has participated in the development of systems to derive energy from the fusion processes for 40 years. We've learned much. We still do not have an operating power-producing fusion facility, however, and many challenging obstacles lie ahead.

Well, someone might ask, why, then, continue to bother with such a difficult technology? Well, the answer is that we seek to provide a reliable source of electric power for future generations. Our oil, our natural gas, and coal are all limited to a relatively short period of time.

Columbus reached our shores about 500 years ago. In much less time than that, fossil fuels which provide for today's energy, for much of today's energy, for all practical purposes, will be exhausted. Fusion promises us a virtually unlimited supply of potentially clean energy.

But our fusion program may be entering a state of reassessment. This, in part, may be the result of not having produced a fusion energy plant, or maybe it's because we have all become much more aware of the pressure on Federal research funds.

Last year we produced an energy policy bill which became public law. Now, less than one year later, Senator Johnston has prepared a new bill, S. 646, called the International Fusion Energy Act of 1993. That bill would essentially focus the fusion program exclusively on the International Thermonuclear Experimental Reactor, ITER, and allow a small sum for research. S. 646 reflects the impatience that in varying degrees we all share, the need to move toward an operational fusion power facility.

Today's hearing objective is to cover four parts of our fusion research and development program: the ITER, deuterium/tritium experiments, the need for a new facility, the tokamak plasma experiment, and new approaches to fusion research and development.

And I'd like to recognize Mr. Fawell at this time for any opening remarks.

Mr. FAWELL. Thank you, Madam Chairman.

If I may at this point ask unanimous consent for inclusion in the record an opening statement from the Honorable Robert Walker, who cannot be here, but has prepared a special statement, making special reference, I might add, to Dr. Randy Mills, who is president of the HydroCatalysis Power Corporation, who apparently lives in Lancaster, Pennsylvania, and I believe that that is within the congressional district of Mr. Walker. So if I may have unanimous consent to have this statement——

Mrs. LLOYD. Without objection, so ordered.

Mr. FAWELL. Thank you.

[The prepared opening statement of Mr. Walker follows:]

OPENING STATEMENT
HON. ROBERT S. WALKER
SUBCOMMITTEE ON ENERGY
MAY 5, 1993

Thank you Madam Chairman. I join with you in welcoming our distinguished panel of witnesses. I extend a particular welcome to a constituent of mine from Lancaster, Pennsylvania, Dr. Randy Mills, President of HydroCatalysis Power Corporation.

Dr. Mills, a member of our third panel on alternative programs, will be sharing with us results from his experiments in producing energy from light-water electrolytic cells, which I believe offers very exciting possibilities. Our other panels will be focusing their remarks on the overall DOE Fusion program to include our experiments with tokamaks.

I believe this to be an important juncture in our Fusion Energy Program. The Department of Energy has provided us with a budget request that continues the R&D programs at Princeton, U.S. involvement in the ITER program, and funding to build the Tokamak Physics Experiment.

Yet there is a move in Congress to concentrate our Fusion R&D on the international effort taking place with our European, Japanese, and Russian partners.

I am inclined to agree with the shift in emphasis of this program to the international arena. I believe in the long run this will be the best use of our limited funds and will prove to our international partners our willingness to share our resources and our research.

Fusion experiments have come a long way in the last 40 years; the progress can be scientifically demonstrated. However, a plateau of sorts has been reached and I believe, in this time of shrinking budgets, that future progress will depend largely on our ability to cooperate with our global partners.

I look forward to the testimony and to the answers to our questions. And thank you Madam Chairman for the time.

Mr. FAWELL. Madam Chairman, I share your view that the fusion program may be entering a state of reassessment. And, in fact, the reassessment may well be long overdue.

I was particularly struck by the recent remarks of a Dr. Robert L. Hirsch, who is not testifying today, but whose remarks were submitted to the subcommittee, made on March 5, 1993, meeting in reference to the Fusion Energy Advisory Committee. Dr. Hirsch, who was once head of DOE's magnetic fusion energy program and is no a vice president of the Electric Power Research Institute, made the following observations:

The DT tokamak and laser fusion reactors are currently envisioned—as currently envisioned, will be extremely complex, highly radioactive, and likely to be highly regulated and costly. Even if DT or laser fusion reactors had the same capital cost as a fission reactor, an enormous challenge, fusion reactors would lose out to advanced fission reactors, which are a reliable, known quantity. These are Dr. Hirsch's statements, not mine.

None of the—the third point was none of the very few fusion-knowledgeable utility people he had spoken with believes the tokamak or laser fusion reactors, as currently envisioned, would be acceptable to the electric utilities.

Fourth, there are some enormous materials problems related to DT fusion. There are no qualified materials today for DT fusion reactors. In the absence of development of a low activity material, a very costly and time-consuming undertaking, you will have to effectively rebuild your fusion reactor every five to ten years and dispose of many times the amount of radioactivity that would come from a fission reactor of the same power level.

And then there ITER. If tokamak reactors, as currently envisioned, aren't acceptable, can ITER be possibly justified? And, another point, if you build ITER, it will become the flagship of fusion and will likely eliminate the chance of serious funding for alternate concepts. And then, also, if what ITER represents is seriously considered in public debate, there is a high probability that ITER will not be supported and the fusion program could collapse.

Dr. Hirsch closes his remarks with several recommendations including: one, scale-up of alternate R&D concepts as fast as possible. Two, don't stop tokamak or laser fusion, but cut them back and reorient them in more acceptable directions. Three, get off the DT fuel cycle to avoid frequent reactor reconstruction, large quantity rad waste disposal, and expensive materials development.

Madam Chairman, I do not pretend to be a fusion energy expert—I'm a refugee from the liberal arts, as I've mentioned several times—but when someone with Dr. Hirsch's knowledge and background and stature makes these kinds of observations, I believe they, of course, deserve serious consideration, and I am hopeful today that witnesses will address themselves to these comments.

I'm also concerned about other aspects of the planned fusion energy program, based upon my inadequate knowledge, I'm sure, including:

One, the role of, and the need for, a new proposed tokamak device, TPX, for which DOE budget documents provide neither a cost estimate, a time schedule, nor an understandable rationale of why it is so important.

And, two, the introduction of tritium into the TFTR later this year, not only will this be done in a heavily populated area, raising perhaps safety and other environmental concerns, but it will also require expensive decontamination and decommissioning of the machine. Is the science we will get worth this cost or would it be more cost-effective to rely on JET, for instance, which already used tritium?

Finally, the continued operation of other tokamaks, including the Alcator C–Mod and the DIII–D tokamaks, in this budget climate means that we cannot afford to pursue promising alternate concepts. Are we really getting our money's worth for them?

All that being said, Madam Chairman, I look forward to the hearing in regard to these concerns to be addressed by our witnesses today. That's just a small little drop, so I'm sure you can handle it all very adequately.

Mrs. LLOYD. Dr. Davies and Dr. Forsen, I think you have your opening statement cut out for you, whether you planned it that way or not.

Mr. Scott?

Mr. SCOTT. Thank you, Madam Chairman.

I look forward to hearing from the witnesses before us today.

The United States has chased after wonders of nuclear fission since the 1950s. Although nuclear fission enjoys a seemingly boundless theoretical value, we're still at least decades away from realizing any tangible benefits to our extensive efforts in developing this technology.

We've already experienced the trials and tribulations of implementing a nuclear energy policy. Hopefully, the hard lessons learned will bode well for the next generation of power production. The American people simply will not accept any new program which does not pay particular attention to their concerns of environmental safety, waste reduction, and cost containment.

This body, thus, finds itself in a position to play a very significant role in our country's energy history, and I'm confident that we'll address this issue with the level of foresight and attentiveness it deserves.

Once again, I look forward to hearing from our distinguished witnesses and learning more about our nuclear fission programs. Thank you very much.

Mrs. LLOYD. Thank you very much.

Mr. Schiff?

Mr. SCHIFF. Thank you, Madam Chairman.

I want to thank you for holding this hearing. I think it's very much time we did an evaluation of our fusion research. Given the dollars for research and development are getting harder to come by, we need to establish where we are and where we're going.

I want to make it clear, I've always had great, great hopes for fusion research. I remain a supporter of fusion research, but we need to evaluate on the record exactly what we can predict in the future.

And thank you for holding this hearing. I thank the witnesses.

Mrs. LLOYD. Thank you very much, Mr. Schiff.

Mr. Swett?

Mr. SWETT. Thank you, Madam Chairman. I'm pleased to be here this afternoon as well as this hearing for what is for me such a fascinating critical field, fusion energy.

I would particularly like to welcome our panelists who will be talking about alternative approaches to fusion. Given our current budget climate, we need to make sure that every taxpayer dollar we spend is wisely invested. Likewise, we need to make sure that we are keeping our eyes open to possible new scientific breakthroughs, wherever they may be found.

I have been interested in alternative approaches to fusion since 1989 when University of Utah researchers Stanley Pons and Martin Fleischmann startled the world when they announced that they had created a fusion reaction at room temperature. As is well known, the effect they were describing was not readily reproducible, and Pons and Fleischmann were branded as frauds.

Since 1989, however, researchers both here in the U.S. and around the world have continued work in the field. In fact, just two days ago, on May 3rd, Pons and Fleischmann had an article published in "Physics Letter A" which documents the remarkable results of some of their recent research.

Here in this country, Dr. Edmund Storms of Los Alamos National Laboratory, who is one of our panelists today, along with scientists at SRI and at various other laboratories and universities around the country, have documented positive results from similar experiences.

Not being a scientist myself, but rather an artist with a little bit of science rolled together to make me an architect, I have to say that as we go into the energy fields and look at research for energy, it's very important that DOE and all of the other agencies that fund this type of research look at all of the alternatives. Good design, good research comes about by trial and error, and much of this has to be spread across a wide field.

My concern is that if we narrow our scope too narrowly, if we exclude opportunities and alternative fuels that are available and not give them any opportunity to grow and develop, I think that we ultimately restrict our possibilities and our potential and could cause great harm to the future of this country.

I look at what our competitors are doing around the world. I see that they are making investments in areas that we are not, and that concerns me, and I hope that today's testimony both in the current funding areas and, of interest to me, in the areas of alternative fusion will bring to light those opportunities and possibilities that will make the future of fusion much brighter in this country and much more varied.

I look forward to hearing the remarks of our witnesses. I thank you all for coming today. And I thank you, Madam Chairman, for the time to make this opening statement.

Mrs. LLOYD. Thank you, Mr. Swett.

Mr. Barton?

Mr. BARTON. Thank you, Madam Chairman. I appreciate the hearing.

I'm especially interested in any comments on the helium–3 nonreactive fusion program. That appears to me to be very positive in its application and somewhat revolutionary. So I look forward to that part of the testimony.

Thank you.

Mrs. LLOYD. Thank you very much.

Mr. Roemer, do you have any opening remarks?

Mr. ROEMER. Madam Chairperson, I would only say that I'd ask unanimous consent; I have a prepared statement for the record.

And I'm very interested in our distinguished panel's testimony today on how to use fusion wisely as a potential alternative, an option in the future, whether that should be an international program, what kind of budget impact it has, and when those kinds of fusion results would pay off in the future, what kind of timeline we're looking at. I'll be very interested in hearing our witnesses, and ask unanimous consent that my entire statement be entered.

Mrs. LLOYD. Without objection, your entire statement will be a part of the record.

[The prepared opening statement of Mr. Roemer follows:]

OPENING STATEMENT OF REPRESENTATIVE TIM ROEMER

Madame Chairman, it seems our troubled economy dictates everything we do these days. We are faced today with determinations to be made for the long-term health and continuation of the American fusion program.

We must invest limited resources wisely, and fusion holds some promise for our future energy needs. But the complexity of the nature of fusion requires that we carefully examine the potential benefits with the costs.

If there are ways that we can expand this technology without busting the Federal budget, we must proceed. But we have an obligation to do this carefully, and this Committee has an enormous responsibility to lead this mission.

Madame Chairman, as is your custom we are gathered here to discuss a timely issue of significant importance. I would like to salute your leadership, and close by saying I look forward to hearing and reading the testimony of our witnesses, who are working so hard on this critical issue before us.

Mrs. LLOYD. And, Mr. Bartlett, do you have any opening statement?

Mr. BARTLETT. Thank you very much, and thank you for convening these hearings.

I have been very privileged to have been able to spend a fair part of my life in science and engineering. So I have a very special and keen interest in this subject.

I think that our country, our society in general, has been somewhat paranoid about nuclear power, and I hope that more education can change that public perception.

I think that whether or not one makes an investment in an area, that one must consider the potential for societal payoff. I am a very strong fiscal conservative, but I will tell you that in the case of fusion energy research, because of the enormous benefit to society—fossil fuels are not forever; in the foreseeable future, indeed, we're going to run short on oil and gas, and then we're left with coal, more difficult to use—so we must have alternative energy sources. Fusion, although difficult to attain, is going to be enormously beneficial. So, from my perspective, one has to make a compelling argument for not funding this research because the cost of the research is so small compared to the total outlays of our government and the potential payoff for society is so great.

Thank you for coming to these hearings today. Thank you, Madam Chairman.

Mrs. LLOYD. Thank you very much.

We are excited about our witnesses today and our No. 1 panel: Dr. Anne Davies, Associate Director for Fusion Energy, Department of Energy; another old friend, Dr. Harold Forsen, senior vice president for research and development at Bechtel Corporation.

Dr. Davies, please proceed with your testimony.

I think you'll have to pull that pretty close to you [referring to the microphone].

STATEMENT OF DR. N. ANNE DAVIES, ASSOCIATE DIRECTOR FOR FUSION ENERGY, U.S. DEPARTMENT OF ENERGY, WASHINGTON, DC; ACCOMPANIED BY DR. HAROLD K. FORSEN, SENIOR VICE PRESIDENT FOR RESEARCH AND DEVELOPMENT, BECHTEL CORP., WASHINGTON, DC

Dr. DAVIES. I have to turn it on, too.

Thank you, Madam Chairman. I'm pleased to be here today to present the Department's budget request for the fusion energy program for Fiscal Year 1994. I really appreciate the support that this committee has provided for the program over many years now.

I have a prepared statement which I would like to submit for the record.

Mrs. LLOYD. Without objection, it will be a part of the record and you may summarize or proceed as you wish.

Dr. DAVIES. Thank you. I will try to summarize, and I will try to address your questions and comments as I go through, but, please, if I miss some, please feel free to come back to me.

I'm glad to hear and I know how strongly the members of this committee feel about the need for future energy sources for the country. The Department is pursuing fusion because of its potential, of our chairman has said, the potential of an affordable and abundant energy source with relatively attractive safety and environmental features.

Let me take a minute here and talk about that. The issue of whether or not the tokamak is too complex, it is complex when compared to some things, but when you compare it to things like a 747, maybe it is not so complex. Our largest Tokamak experiment in the United States operates with something like 80 percent reliability, and it's still a scientific research experiment. It is not meant to be a reactor that produces power at this stage.

When you talk about the cost of fusion, I think we really ought to start with the safety and the environmental aspects of fusion because without those characteristics an energy source can have infinite cost. If people are unwilling to buy it, the cost is infinite.

The fusion reactor, as we conceive it, would produce in volume as much radioactivity as a fission reactor, but with much less energy density, and that means that you don't worry about the decay heat. It's a much safer situation than the fission reactor that Bob Hirsch was comparing it to.

Also, the radioactivity associated with the fusion reactor is in the structure. It's not in the fuel elements like a fission reactor. It's in the structure, which means it's relatively easy to manage. You don't worry about it getting into the air. You don't worry about it getting into the water supply. You do have to handle it remotely. You do have radioactivity.

With the selection of materials for the structure of a fusion reactor, we believe you can reduce the radioactivity orders of magnitude below what you would get with steels, which is the thing that Bob Hirsch compares it with when he does this. And even with steel, fusion reactors have real advantages over fission reactors, as I was describing.

And when you look at the cost of fusion reactors, we don't know what fusion reactors are going to cost yet. We've done design studies and we've tried to make estimates. And we've been doing this for a number of years. I think those estimates are more useful when we're comparing different fusion reactor concepts, but if you want to compare them with the cost of fission, they look like they're in the same ballpark. When you look at the best possible, best ever experience with fission, that's cheaper, but when you look at the median cost of fission reactors on line today, the fusion costs look comparable or lower.

So I think that when you look at cost, fusion reactors appear to be in the same ballpark as fission reactors. I'm not sure where Dr. Hirsch gets his figure of 50 percent higher, which is a number I've heard him quote.

Concerning the issue of alternate concepts, other than Tokamaks, several of you mentioned this point. This is a subject that is debated and debated in the fusion community time and time again. Under budget constraints, we've often curtailed our programs in research other than Tokamaks. There is not a person in the fusion community who likes that. Everybody who looks at the program says anything this long term ought to have some room for innovation, some resources set aside to look at improvements. I agree with that, and we've set aside a modest amount of money this year in order to entertain proposals for small-scale experiments that could improve on the tokamak design to investigate or entirely different concepts, and those proposals are under review right now. We hope to get the results soon.

But we agree with that point. It is very difficult for us, too, when we have to scale back or eliminate some of our concepts, and we've eliminated a number over the years, not for technical reasons, but for budget reasons.

Let me go back and talk a little more from what I prepared. I wanted to answer your questions about the tokamak as a concept. Fusion is not just something that the Department is doing. At this point President Clinton's "Vision of Change for America" identified fusion as part of the program that the country should embark on for the sake of its long-term economic future.

We in the program, those of us who are trying to develop fusion, appreciate that kind of support. We're working hard to try to justify it. You said that it's a very difficult challenge to develop fusion, and you're right, it is.

A year ago when we were here, we reported on results from the very first magnetic fusion experiments, using deuterium and tritium, the fuel that fuses most easily in the Joint European Torus, the Euratom experiment that's located in the United Kingdom. In that experiment, 2 megawatts of fusion power was produced in a short pulse length of about 2 seconds. Dr. Rebut, who's going to appear before you later today, was the Director of the Joint European Torus at that time, and he is now the Director of ITER.

Since the time we were here last year, we have made progress on preparing to use tritium in the Tokamak Fusion Test Reactor at Princeton. We've completed a major set of environmental reviews and have just recently brought 100 curies of tritium onsite to begin to test the tritium-handling system for TFTR.

We have one more major operational readiness review scheduled, and then we expect to begin the deuterium/tritium experiments in September with the production of 10 megawatts or more of fusion power by next year, the first of next year. These experiments are important to us. They are going to be our first opportunity to study, in detail, with a complete diagnostic system a tokamak plasma that is producing significant amounts of fusion power. I expect that Dr. Davidson will want to talk to you about this more. We have had this program reviewed by our advisory committees to make sure that it's worth the money that it is going to cost to do it, and we believe that scientifically it is. And then we expect that some of our people from TFTR will go to JET as they begin their tritium experiments in the following year.

Another major accomplishment of this year was the signing of the Engineering Design Activities Agreement for ITER last July by the United States, the Russian Federation, the European Community, and Japan. Key personnel assignments have been made. The three co-centers are operating, including ours in San Diego, California. The Director of the project and his senior staff are selecting members of the Joint Central Team and they've produced a reference design and a preliminary work program. They've done a lot of work in a fairly short time.

In the United States we have had excellent support from the State of California; from the University of California at San Diego; their contractor, Scientific Applications Incorporated; and the San Diego business community as well in operating our co-center, hosting our co-center. There are three co-centers. One is in the United States, one in Japan, and one in Germany. Each is to be staffed by an international team that takes a part of the ITER design, and it's all coordinated through the San Diego co-center.

As you know, the ITER work that will be assigned to the United States will be carried out through the U.S. Home Team. We have a new home team leader, Dr. Charles Baker from Oak Ridge, who will be with you a little bit later. And he has reorganized the U.S. ITER effort and he has also led our effort to assist the Director as the Joint Central Team is getting itself organized.

Our home team has also brought industrial partners on board in all the key areas of research and development and also design, so that industry will already be with us when the ITER Director assigns tasks to the United States. We don't want to waste any time once we have task assignments. We want our industry people to be up to speed. We want our industry people to be knowledgeable and have the experience base, so that when it's time to build ITER, our industries will be able to compete, and compete successfully, to build components for ITER.

Most of the rest of our program is also focusing more and more on ITER, everything from our theoretical work to our experiments, large and small. A particularly positive set of results this year came from the DIII–D experiment at General Atomics. In one set of experiments, very good confinement was produced, 50 percent better than seen before. In another set, very high-pressure plasmas were produced. Both of these results argue very well for ITER and, in fact, for a tokamak reactor.

The DIII–D, along with the Alcator C–Mod experiment, which is just coming into operation at MIT, are going to continue to support the design of the ITER, in particular, with experiments in a very critical area, that of the diverter physics and technology. The diverter is the part of the tokamak that sweeps away impurities and particles as they near the edge of the plasma, the edge of the vacuum vessel, and it prevents impurities from coming back into the plasma. It is the key technical issue associated with ITER, and both DIII–D and Alcator C–Mod are going to help with that.

As you know and mentioned, the magnetic fusion program has become more and more international over the last decade, but we understand that in order to be an effective international partner a country needs to have a strong domestic program as well. For a number of years now, about 15 years, the magnetic fusion program has been struggling with its future in the United States. The Tokamak Fusion Test Reactor and the DIII–D were both conceived in the early seventies. That is a long time ago, and there has been a great deal of experience, knowledge, and innovation developed since that time.

Both of those experiments have contributed much more science than we originally, any of us originally, expected, but both of them are going to come to a point of diminishing returns in the near future. TFTR, at the end of its deuterium/tritium campaign in September of 1994—it's a one-year tritium campaign—and then DIII–D a few years later, probably by the end of this decade.

So what is the right domestic program for the United States as we're participating in ITER? We considered a number of options, only to conclude each time that the cost of that option was too high. In the fall of 1991, the Secretary of Energy Advisory Board set up a Task Force on Energy Research Priorities. They looked at all the major projects under energy research. One of those was a fusion devise. Their conclusion and their recommendation to the Department was that we should be working on a device in the half billion dollar class that would lead to tokamak reactor improvements and also contribute to improved operating modes for ITER.

In the fall of 1992, the Chairman of the Fusion Energy Advisory Committee presented its conclusions on the Tokamak Physics Experiment to the Task Force that had made the recommendation the year before. This Task Force endorsed the Tokamak Physics Experiment as fully meeting their objectives from the year before.

With your permission, Madam Chairman, I would like to submit the reports of these committees for the record.

Mrs. LLOYD. Without objection, it will be included.

Dr. DAVIES. Thank you.

TPX is a national facility. It's being designed by people from all over the U.S. program. It would conserve resources by using the Tokamak Fusion Test Reactor facilities at Princeton, but it is meant to be a national facility. If successful, TPX would lead to a more compact and a more cost-effective steady state tokamak reactor. ITER is designed to operate for long pulse, but requires external power to drive the current in a tokamak for very long pulses. The idea behind TPX is to produce as much current internally in the plasma as possible, so that you don't have to provide very much power from the outside. That would make it more compact. It would make it more cost-effective as a reactor concept. It is something that the U.S. fusion community has identified as an important reactor improvement for many years now, and only in the last couple of years has the particular idea of TPX come to the fore in such a way that we feel like we have something that we can test.

We've done what we can and will do more with the existing facilities, but TPX would be the only facility in the world that can test these theories at long extended pulse length, essentially steady state. By virtue of doing these tests, which are really aimed at a demonstration reactor, TPX would also help us in planning how to run ITER during its extended performance phase, where we hope to drive current and have ITER operating for very long pulse lengths.

We are also planning to have industry involvement in TPX, both in the design and in building it. Industry involvement here would be a beneficial complement to industry involvement in the ITER program and would help equip our industries to build the ITER components.

The TPX project team has completed a conceptual design and we had a committee of 32 international experts in physics, engineering, project management, cost estimating, and so forth, review it. They have endorsed it with very modest recommendations for changes.

The Department is right now conducting an independent cost estimate, and we expect to be ready to begin engineering design in October. The reason our budget submission did not have a total estimated cost or a schedule is because we wanted to finish the conceptual design review before we submitted a cost estimate to the Congress.

We also understand that the funding profile will determine when the project is completed. We are hoping to complete it sometime between 2000–2001, depending on the funding profile.

And I should tell you that the cost estimate in 1993 dollars looks like it's about $550 million, but we're waiting for the Department's independent cost estimators to confirm that.

Before I close, let me say just a word about inertial fusion energy. In the fusion energy program, we have a small effort on components needed for energy applications of inertial confinement fusion, which is the other major way of producing fusion reactions on earth. The target physics for ICF is conducted by the Office of Defense Programs in the Department as part of our weapons research and development program. Our work in the Office of Energy Research is primarily right now on the accelerator physics for a heavy ion driver.

Our Advisory Committee has just completed a review of the inertial fusion energy program at our request and has found it to have high technical merit. Our problem is how to adequately fund it, given the extremely difficult budget circumstances we're facing. We have not yet decided how to respond. In fact, just before I came over here, I received by fax the letter from our Advisory Committee, so we haven't even had a chance to read it. But we're going to consider it very seriously. I did participate in the meeting of the Advisory Committee. I know what their deliberations were.

This same problem of funding applies to several other important areas of our program, including alternate concepts and the development of low activation materials. In these latter areas, we're attempting to ameliorate the problem through international collaboration. We do need to develop low activation materials; the world has agreed on that, and we're working with our international partners through the International Energy Agency to see if we can do a design effort together, so that the world can get on with developing the materials that would make fusion reactors as attractive as we think they could be.

Thank you again for the opportunity to speak to you today, and I would be happy to answer any questions.

[The prepared statement of Dr. Davies follows:]

Statement of N. Anne Davies

Associate Director of the Office of Fusion Energy

Office of Energy Research

U.S. Department of Energy

before the

Subcommittee on Energy

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

May 5, 1993

Madam Chairman and Members of the Subcommittee:

I am pleased to be here today to present the Fiscal Year (FY) 1994 budget request for the Fusion Energy program, which is supported by the Office of Energy Research under this Subcommittee's jurisdiction.

The world will need new sources of energy in the next century, and fusion has the potential to provide an economically affordable, abundant energy source with relatively attractive safety and environmental features. The development of fusion as an energy source could contribute to the energy security of the United States, provide economic growth potential, and make us a supplier of energy technologies to other countries.

Fusion energy has a number of characteristics that make it an attractive potential energy source. Due to its wide availability, fusion fuel cannot be embargoed, and it is essentially inexhaustible. The non-radioactive component of fusion fuel, deuterium, can be obtained from sea water. The other fuel component, radioactive tritium, can be produced within the fusion reactor itself, eliminating both the risk and cost involved in transporting radioactive fuel. Although the fusion reaction is a nuclear one, fusion power plants constructed with the proper materials have the potential to be environmentally attractive. Also, a fusion reactor can be designed to be inherently safe without the need for active safety systems. Since fusion reactors will contain only a small inventory of radioactive fuel, the possibility of severe, uncontrolled events is eliminated. Furthermore, the fusion process produces no combustion products or greenhouse gases.

The Congress and the Administration have recognized the potential of fusion. The Energy Policy Act of 1992 directs the Secretary of Energy to conduct a fusion energy program that "...by the year 2010 will result in a technology demonstration which verifies the practicability of commercial electric power production." President Clinton's "Vision of Change for America" states "...fusion offers the promise of abundant energy from readily available fuels with low environmental impact" and includes fusion research in the Administration's Economic Investment Package.

Now let me provide some background information on our magnetic fusion energy program strategy, goals and elements, including those referred to in the Energy Policy Act.

In 1990, the Department's Fusion Policy Advisory Committee concluded an in-depth review of the fusion program. As a result of that review, the Department established a policy to proceed with a goal-oriented program with specific milestones for the development of fusion energy. The objective of technology demonstration cited in the Energy Policy Act is consistent with the magnetic fusion energy program's long-term goal of having an operating Demonstration Power Plant by about 2025 and an operating commercial power plant by about 2040. Achieving these goals requires that we gain an understanding of the complex processes involved in fusion and that we develop the technologies and the industrial infrastructure needed for the practical application of fusion energy.

Magnetic fusion energy activities in the U.S., and indeed worldwide, have been focused for many years on the tokamak concept, a donut-shaped magnetic confinement design invented by the Russians. The tokamak is the leading geometrical concept used for confining the fusion fuel (i.e., plasma) by magnetic fields. The major U.S. experimental tokamaks are the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory, the Doublet III-D (DIII-D) at General Atomics, and Alcator C-Mod at the Massachusetts Institute of Technology (MIT). The worldwide emphasis on the tokamak concept is based on numerous, cumulative accomplishments in advancing physics understanding and developing related hardware and engineering systems. The improvement in tokamak performance has increased by a factor of more than a million over the past 20 years. We expect to demonstrate a 200-fold increase in performance over previous TFTR results when we conduct experiments using deuterium and tritium fuels in TFTR in FY 1994. These results are expected to set a world record for fusion surpassing the performance achieved in the Joint European Torus in 1992. The amount of additional performance improvement required to produce a practical fusion reactor is only a factor of about 10. This final factor of 10 could be reached by the International Thermonuclear Experimental Reactor (ITER) by about 2010.

While past accomplishments establish a sound basis for proceeding with fusion energy development to meet the goals we have established, continued progress requires the development and construction of new, larger, and more costly facilities. Given the general funding constraints being experienced in fusion programs worldwide, it seems clear that the most effective means to realize our goals is through integrated programs of international collaboration to

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demonstrate the scientific and technological feasibility of fusion power. The U.S. has been and continues to be a leader in encouraging this approach by fostering international collaboration in all aspects of fusion science and technology development. This collaboration is exemplified by the ITER project, a four-party effort involving the U.S., the European Community, Japan, and the Russian Federation. The President has called ITER "the centerpiece of the research effort in magnetic fusion energy...."

The objective of ITER is to demonstrate the scientific and technological feasibility of using magnetic fusion energy for the production of electricity. The four ITER partners successfully completed a conceptual design in 1990 and have initiated a six-year Engineering Design Activities phase to complete the design and supporting research and development of the device. The formal ITER Agreement and its first Implementing Protocol were signed in July 1992. This Agreement affirms the principle of equality of the parties with regard to their status in, their contribution to, and their benefits from their collaboration on ITER. The cost to the U.S. of participating in this six-year effort is estimated to be about $450 million.

While it must be made clear that no commitment has been made by any of the parties to construct ITER, the project does play a pivotal role in our strategy to develop fusion as an energy source. If constructed, ITER would provide: (1) an important part of the physics data base needed for a demonstration power reactor, (2) actual operating experience with many of the reactor technologies needed for fusion power, and (3) an opportunity for major industrial involvement in the fusion program.

The ITER Agreement provides for the overall design work to be performed by a Joint Central Team staffed by scientists and engineers from all the international parties. Specific component and systems design tasks and technology development will be accomplished by the four parties using their home industries and laboratories.

The U.S. Home Team is managed from the Oak Ridge National Laboratory, assisted by personnel drawn from several other National Laboratories and universities. Solicitations have been made for the participation of industrial teams to work with laboratories in accomplishing the tasks assigned to the U.S. Home Team by the ITER Director. Contracts have already been awarded to industrial teams including General Dynamics, Westinghouse, McDonnell Douglas, Rockwell International, Ebasco, General Atomics, Grumman, Pittsburgh-Des Moines and CIMCORP to participate in ITER research and development activities. The University of Wisconsin and the University of Illinois are also participating with some of these industrial groups. In this way, knowledge about the ITER design and component development skills will be transferred to U.S. industry in order to prepare them to compete successfully in the construction of ITER.

The ITER Joint Central Team, which is responsible for integrating the activities of the Home Teams into a coherent design, is located at three sites: San Diego in the U.S.; Naka in Japan; and Garching in Germany; with the ITER Project Director and his project integration staff in San Diego.

At the end of this engineering design phase, all data necessary to make a decision on ITER construction will be available to the international parties.

While it has been assumed that the selection of a site for construction would come at the end of this six-year engineering design phase, an earlier decision, if possible, could allow a smoother transition to construction and should reduce costs.

While ITER plays a central role in our strategy for moving toward a demonstration reactor, it is also necessary to continue to conduct a strong domestic program to support the ITER project and to put the U.S. in a position to use the information gained from ITER for a follow-on demonstration power plant and ultimately for commercialization. Other key elements of the U.S. domestic tokamak program include the deuterium-tritium experiments in TFTR mentioned earlier, physics research to support ITER and to improve the tokamak concept, and the development of the components and systems that will be used in ITER and in subsequent fusion reactors.

Other major activities are required in order to make fusion a practical energy option. Based on recommendations from the Secretary of Energy Advisory Board Task Force on Energy Research Priorities and the Fusion Energy Advisory Committee, the Department, through a national task force of fusion scientists and engineers, has developed a conceptual design for an experimental facility to serve as a national focal point for fusion experimentation in the first decade of the 21st century. We are pleased that this new device, referred to as the Tokamak Physics Experiment (TPX), is included in the Administration's investment package and the Energy Policy Act. The TPX, which would be sited at the Princeton Plasma Physics Laboratory and would replace the TFTR, would offer a unique facility to investigate tokamak improvements, which, if successful, could lead to the design of a cheaper, more compact, simpler fusion power demonstration reactor. If started soon, TPX could also lead to improved operating modes for ITER. In addition, this project would provide the scientific focus to maintain the vitality of the U.S. program between the time of completing the TFTR program and the start-up of ITER. It would also provide a mechanism for increasing U.S. industrial expertise in fusion and helping U.S. industry compete for possible ITER construction contracts. The Fusion Energy Advisory Committee has strongly recommended proceeding with the detailed design and construction of TPX for operation in the year 2000.

Another area of important research, the development of low-activation materials, such as vanadium and silicon carbide, is essential for the realization of the potential environmental benefits of fusion energy. The development of these materials could reduce the amount and lifetime of radioactive waste from fusion reactors by factors of hundreds up to one million. The development of such materials will be costly and require many years. For instance, it will be necessary to conduct candidate materials testing in a fusion neutron source facility capable of producing the same amount of neutrons as would be produced in a fusion reactor. We have initiated discussions with our international partners on how such a facility could be developed as a jointly shared international resource. So far, there is agreement that an accelerator-based, beam-target facility is the proper choice.

In this era of increasing budget stringency, the U.S. program has focused research efforts on fewer, more effectively used experimental facilities, using staff scientists augmented by those from other institutions. All major confinement experiments at both the Los Alamos National Laboratory and the Lawrence Livermore National Laboratory have been closed down; the Advanced Toroidal Facility at the Oak Ridge National Laboratory is still being prepared for possible future operation. Scientists from those programs are now participating in experiments at the TFTR, the DIII-D, and the Princeton Beta Experiments-Modified (PBX-M) facilities. The PBX-M will be shut down at the end of this year in order to focus resources on TFTR.

In prioritizing activities for the Magnetic Fusion Energy Program, the highest priority is the introduction of deuterium and tritium (D-T) fuel in the TFTR facility and carrying out the planned experiments. Another high priority is full participation in the ITER engineering design phase, including conducting research and development in the U.S. to support the design of ITER. Experiments on DIII-D and Alcator C-Mod at MIT are addressing key ITER design issues and, therefore, are receiving funding priority. In order to improve the demonstration reactor concept, priority is also being given to the design of the TPX, a long-pulse tokamak. The Princeton Beta Experiment and the Advanced Toroidal Facility were built to investigate improved tokamak physics, but they are given a lower priority at this time and neither will be operating in FY 1994, as mentioned above. The base program, which supports ITER, TPX and the development of materials and nuclear components required for a demonstration power plant, will continue below the FY 1993 funding level because of the higher priorities identified above.

In addition, a smaller effort is conducted on the Inertial Fusion Energy concept. The objectives are to develop components, such as a high-efficiency, high repetition-rate driver and targets, and investigate various reactor concepts that will use the target physics developed by the Department's Office of Defense Programs.

FY 1994 FUSION ENERGY BUDGET REQUEST

The FY 1994 budget request for Fusion Energy is $347.6 million. This includes $316.6 million for Operating Expenses, $16.0 million for Capital Equipment, and $15.0 million for Construction (Attachment 1). This supports four essential program elements for magnetic energy, including conducting D-T experiments in TFTR, participating in the engineering design phase of ITER, initiating the detailed design of the TPX, and continuing a base program of physics and technology support. In addition, it supports development of inertial fusion components for energy application.

The operating budget consists of six subprogram activities. For the Confinement Systems subprogram, $157.4 million is requested for Operating Expenses. Preparations will be completed and experiments using D-T fuel will be carried out in TFTR beginning in late 1993. The purpose of these experiments, which are ultimately designed to produce over 10 megawatts of fusion power, is to conduct the first detailed studies of tokamak confinement of fusion-produced alpha particles. In addition, the FY 1994 budget includes funding to continue R&D and prototype development to support the initiation of a design-only construction project for the TPX at Princeton, advancing the tokamak reactor concept and increasing the U.S.'s ability to contribute to and benefit from the ITER program. The TPX would explore many of the physics and technology improvements required for a demonstration fusion power plant. The TPX will have the capability to conduct experiments that could last about 500 times longer than those which can be conducted in present machines like TFTR. The long duration experiments will simulate conditions of continuous operation that would be necessary in power reactors.

Other tokamak experiments, including the DIII-D tokamak at General Atomics, and the Alcator C-M tokamak at MIT, will be used to provide information to be used in the design and operation of ITER and the design of TPX. DIII-D will focus on experiments using more efficient techniques to "drive" the current in the plasma with high plasma pressures. Alcator C-M will study techniques to confine the fusion plasma under high magnetic field conditions with various divertor (i.e., impurity control) configurations for limiting the interaction of plasma particles with the vacuum vessel wall, one of the critical issues faced in the ITER design. International collaboration by our scientists will be used to keep abreast of developments on alternate confinement concepts, such as reversed field pinches, stellarators, and compact toroids, since the primary experiments in the U.S. in alternate confinement concepts have been either terminated or postponed.

The FY 1994 budget request also includes $59.8 million of operating funds for the Applied Plasma Physics subprogram to support both experimental and theoretical research on basic fusion concepts and plasma physics. It supplements research in the Confinement Systems subprogram by developing and using new diagnostic systems, by developing plasma heating and control concepts, and by producing basic scientific data necessary to design and conduct reactor-scale fusion experiments. A significant portion of this activity is focused on improving the understanding of how energy and particles are lost from the plasma by mechanisms that "transport" them across the magnetic fields that confine the plasma. It also supports small-scale studies on selected non-tokamak fusion energy concepts.

The $81.3 million of operating funds requested for the Development and Technology subprogram is primarily for the support of ITER. The funding requested for ITER is to provide the U.S. share of the Engineering Design Activities phase of the project, which includes the engineering design, supporting technology research and development, and development of model components that could be scaled up to full size. The costs of hosting the San Diego Co-Center for the ITER Joint Central Team are covered, as well. This subprogram also supports a base technology program to develop magnets, heating systems, blankets, and materials for existing and planned experiments. Funding is also included in this subprogram for the long-range development of advanced materials that will not become highly radioactive during service in the reactor, thereby enhancing safety and simplifying waste disposal.

The FY 1994 Operating Expenses request also includes $4.0 million for the continuing R&D in the Inertial Fusion Energy subprogram. The primary effort will be focused on the physics of heavy ion acceleration. This program will rely on the continuing development of inertial fusion target physics and ignition characteristics information supported by the Department's Defense

Programs' budget. Where possible, international cooperation will be pursued to speed overall progress in inertial fusion energy.

The Operating Expenses request also provides $9.2 million in Program Direction funds for the salaries, benefits, travel and other expenses associated with 81 full-time equivalents required to administer the Fusion Energy program by the Headquarters staff and those at DOE Field Offices; and $4.9 million in the Planning and Projects subprogram to support the program's legal obligation to the Small Business Innovation Research Program.

The FY 1994 Capital Equipment request of $16.0 million provides essential hardware to support the overall program. This includes diagnostic and computer equipment, power supplies, and other components for experimental facilities. The increase over FY 1993 is primarily associated with capital equipment improvements at DIII-D.

Of the $15.0 million in FY 1994 Construction funds, $13.0 million is required for the TPX project to initiate Title I design activities and the procurement of architect-engineering services. The remaining $2.0 million is for General Plant Projects, which provide for the continuing minor alterations and modifications necessary to meet health, safety, and programmatic requirements and to protect the Government's investment in its facilities.

This concludes my prepared testimony. I would be happy to answer your questions.

Attachment 1

Fusion Energy
Budget Authority
($ in millions)

	FY 1992	FY 1993	FY 1994 Request
Operating Expenses			
Confinement Systems	$ 180.3	$ 164.2	$ 157.4
Applied Plasma Physics	61.7	61.9	59.8
Development and Technology	56.6	66.4	81.3
Planning and Projects	0.3	4.8	4.9
Inertial Fusion Energy	8.2	6.8	4.0
Program Direction	7.5	8.8	9.2
Subtotal	$ 314.6	$ 312.9	$ 316.6
Capital Equipment	$ 13.0	$ 14.1	$ 16.0
Construction			
Tokamak Physics Experiment (94-E-200)	0	0	13.0
General Plant Projects (GPE-900)	2.0	2.0	2.0
Fire and Safety Project, PPPL (92-E-340)	2.6	2.2	0
Subtotal	$ 4.6	$ 4.2	$ 15.0
Total Fusion Energy	$ 332.2	$ 331.2	$ 347.6

Mrs. LLOYD. We appreciate not only your knowledge, but your comprehensive review that you provide for us.

Dr. Forsen, please proceed.

Dr. FORSEN. Thank you, Madam Chairman and Members of the Committee. I'm pleased to have the opportunity to testify before your Committee on the progress and industrial perception of fusion energy research in the United States.

I'm a Senior Vice President of Bechtel Corporation responsible for its technology group. I also currently serve as the Chairman of the ITER Industrial Council.

My written testimony better addresses the issues raised by Mr. Fawell, and I would ask that it be included for the record, if possible.

Mrs. LLOYD. Without objection, it will be included.

Dr. FORSEN. The world fusion program to develop the Tokamak concept as a power-producing reactor continues to make considerable progress. However, there remains much to do before we can really assess the economic potential of fusion systems and it is essential that we get on with this development.

It is very important to proceed with DT burning in the TFTR at Princeton. Understanding the resultant alpha particle physics is still an experimental unknown in fusion systems. It is also important to recognize that there are several additional large-scale experiments that are required before the science and engineering of fusion can really be fully evaluated. These experiments have to do with steady state operation, materials testing, and blanket design engineering for power production. Several of these can be built and operated as a result of international collaboration.

As an aside here, let me reflect on the great benefit that this international collaboration has brought. Prior technical exchanges dating back to the late 1950s with the European Community, Japan, and the former Soviet Union have made possible the great progress in understanding the difficult physics of confinement of high energy density plasmas and, in particular, Tokamaks. This has helped us develop scaling laws that exist for no other confinement system and to recognize that the understanding of plasma science is highly configuration-specific; that to understand what scaling and control might exist for a configuration other than a Tokamak would take a program of perhaps equivalent time and cost to what has already been undertaken.

For these and other reasons, international collaboration has confirmed that the Tokamak approach is the most attractive, relatively near-term approach. Today the ITER is the centerpiece device for the development of scientific and technological data necessary to proceed with fusion power production. Drs. Rebut and Baker will describe it further, but this machine should give us the understanding of ignited burning plasma and a real handle on the technology of power production. It must receive our full support for both its design and construction, and, further, the United States should make every effort to identify, develop, and offer sites for its construction.

The U.S. program must continue to support and complement this international effort, and U.S. industries must begin to play a greater role in the design, construction, and operation of these devices.

Specifically, the TPX plan for Princeton is the next important program for the United States. This will be described more later by Dr. Davidson, but it will be the first major new U.S. construction since 1976. It's currently planned to have broad industrial participation in its design and construction, and industry applauds this approach.

It's appropriate to mention that Tokamak fusion power as conceived today is a collection of many subsystems such that an industry can develop where many players participate as opposed to fission reactors where the sophisticated nuclear engineering issues of reactor core physics demand a central design and a highly integrated fuel supplier.

Currently, the fusion industrial community includes aerospace companies, fission reactor manufacturers, architect-engineers, specialty component suppliers, and others. We look to the ITER and TPX as real opportunities to learn, contribute, and prepare for the future when the U.S. could be in a position to supply and possibly operate these systems around the world.

Having said this, it is also important to note that the Tokamak can be improved as our understanding improves. The world program does, and U.S. programs should, include some flexibility in its funding to look at Tokamak concept improvement and alternate concepts. This should be a visible but limited activity with much of it centered at universities where the basic training takes place.

Too much second-guessing or paper-driven promises will only erode the significant progress and understanding that has been made to date in Tokamaks. A lot of money has been spent and a lot of time and effort devoted to igniting and controlling a DT plasma. We're almost there, and until this has been accomplished, there is really no way to project what fusion power has to offer and at what cost.

For an industry to manufacture these power sources and for the utilities to operate them, either directly or as a wheeler of their power, the fusion system has to be considerably better defined than it is today. My message is that we should get on with the development.

Thank you again. I'll answer questions.

[The prepared statement of Dr. Forsen follows:]

STATEMENT OF

DR. HAROLD K. FORSEN
SENIOR VICE PRESIDENT, BECHTEL CORPORATION

TO THE

SUBCOMMITTEE ON ENERGY
OF THE
HOUSE COMMITTE ON SCIENCE, SPACE AND TECHNOLOGY

May 5, 1993

Madame Chairman and members of the Subcommittee, I am pleased to have the opportunity to testify before your Committee on the progress and pace of fusion energy research in the United States, and particularly the possible private or utility sector interest in fusion power plants. I am a senior vice president of Bechtel Corporation and responsible for its Technology Group. Also, I currently serve as the Chairman of the ITER Industrial Council. ITER being the International Thermonuclear Experimental Reactor.

Researchers in magnetic fusion continue to make impressive progress in understanding the physics and technology issues associated with producing, heating and confining ionized gasses in the temperature and density ranges necessary for fusion power production. Recent results in all large scale international machines such as the JT-60 in Japan, the JET in Europe, and at home in Doublet DIII at General Atomics and the TFTR at Princeton have been most encouraging. That is the tokamak approach continues to yield to the necessary understanding which will permit the next steps in fusion power development. I want to come back to this point in a minute but an aside here seems appropriate.

The program needs to have some funds available to support alternate and/or improved approaches to the tokamak configuration as a power reactor. On the other hand, understanding nature and the physics of plasma confinement has been a difficult and expensive task for the nations pursuing fusion power over the past three and a half decades. We need to understand what the tokamak approach will give us in a safe, environmentally benign and earth resource based energy producer; what will be the economics when our understanding of this most favored approach, by all nations working in fusion, is sufficiently complete to fully design and build the first power producing reactor; and what will these economics compete with and what options are available?

I worry very much about not getting on with D-T fueled tokamaks at the expense of too much second guessing of what might be cheaper, smaller or fueled with more exotic, remote fuels. To envision an R & D program that strives to provide complete understanding of plasma containment and heating that any conceived configuration of

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fuel cycle might require, is to delay the economic and hard engineering knowledge perhaps indefinitely.

Returning to the program's progress and plans. The planned DT burning experiments in the TFTR at Princeton during next year are long overdue. These important tests will give us some indication of the effects of alpha particles on both energy transfer and containment which will be a key to the success of ITER. Further, the necessary data on confinement scaling in tokamaks for these heavier isotopes of hydrogen is an important piece of the same knowledge base necessary to design ITER and subsequent fusion power plants.

Moving to the specifics of ITER, you will hear considerably more about this important international collaboration from Drs Rebut and Baker. Let me just say that this collaboration in tokamak fusion is very important. The fusion community has had an excellent international working relationship since the late 1950s and the difficulty of understanding this new science of hot plasmas has been significantly reduced through these relations. Designing and building ITER should proceed as quickly as possible, and the United States should make every effort to develop and propose a host site for its construction.

The necessary data to take the program to a demonstration power reactor will require more than ITER can provide, however. ITER has a physics and a nuclear technology mission but the reactor engineering, materials, environment, and health and safety needs of a licensable power plant requires specific data not easily acquired in a large physics machine. At least two additional Facilities are needed and these too can be international in funding and operation. They include a modest scale Materials Test Facility and a larger scale Blanket Test facility - sometime referred to as a Volumetric Neutron Source. Their early design and construction are key to the science and engineering needs of fusion as a reliable, sustainable, operable, maintainable and, of course, economic power plant. While these tight economic times make it hard to think about some of this, these test facilities are just as important to the engineering goals of fusion as ITER is to the physics and technology goals.

Similarly, the needs of the United States program in tokamak concept improvement and the long-term operation of fusion systems means that the Tokamak Physics Experiment (TPX), under conceptual design for Princeton, is also a key element in our understanding. Further, the TPX is an important opportunity for U. S. industry to gain experience in the design and construction of these tokamak devices to prepare us to compete for the construction of ITER.

Least you think of these several key relatively large scale experiments as yet a lot to think about, authorize and fund before the design, construction and operation of a demonstration power plant is possible - we need to recall the development of fission power reactors in the United States. By the late 1950s the United States had constructed six reactor approaches that could be considered commercial prototypes. By 1962 there were some 233 different reactors and critical piles of various types and

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sizes operating which were American built - all before any economically competitive reactor was ordered by a utility. Fusion is different, but the information needs are still critical to its longer term success. The experimental devices in the Department of Energy's development strategy for fusion are essential and should proceed at a reasoned pace. In particular, the TPX is the next key construction step and you should hear more about this from Dr. Davidson.

Let me conclude with a few comments about industries perspective on fusion. I am sure you are aware of the frustration the utilities have over nuclear fission power - light water reactors. Operating costs that were never envisioned, waste disposal problems the government has said it would solve but has yet to, and licensing and regulatory issues that scare some operators away from upgrades and modifications that could meaningfully extend their life and performance. For these utilities, and for the industry that designed, built and warranted the reactors, it is very hard to get overly excited about a third generation of nuclear reactors called fusion. Especially those some forty years away. Nonetheless, there is enthusiasm among the potential suppliers of this technology. And there are many reasons for this.

First is the safety issue, on fusion compared to fission, that we all anticipate the public and the regulators will understand and accept. There can be no criticality or melt-down issues like Three Mile Island or Chernobyl that spread fear and panic throughout the world. The proliferation concerns of many, due to the perceived availability of fissile materials to make clandestine weapons, is not an issue in fusion such that power plant security is dominated by OSHA safety and not a nuclear threat. While radioactivity is produced in any fusion system that uses naturally occuring deuterium as a fuel component, this can be minimized by using light activation materials which we believe can be developed. Of course, this is another reason that the program needs a fusion energy spectrum neutron source for materials development.

On the development issue we understand that historically the utilities have been able to ameliorate the impact of new technology by placing the cost of such plants in their rate base. More recently, this has taken on a new meaning. With the deregulation of utility generation and the advent of project financed Independent Power Producers (IPPs), the owners of electric power generating facilities are required to place greater emphasis on certain, specific characteristics of new technologies. These include:

o <u>Reliability:</u> IPP power purchase contracts are tied to the ability to deliver energy <u>and</u> capacity, particularly on peak demand.

o <u>Simplicity of operations:</u> complex systems are inherently more difficult to operate and maintain with a concomitant impact on personnel, training, and so forth.

o <u>Size:</u> utility needs dictate the size of new power generating plants or power purchase options.

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o New technology syndrome: since new plants are project financed, the lenders tend to shy away from first of a kind (FOAK) plants. This may require that the developers of the technology have a significant ownership share of the FOAK plant.

This lends itself to how fusion is developing. The fusion reactor as conceived today is a collection of many subsystems such that an industry can develop where many players can participate as opposed to fission reactors where the sophisticated nuclear engineering issues of reactor core physics demands a central design and highly integrated fuel supplier. Currently, the fusion industrial community includes aerospace companies, fission reactor manufacturers, architect engineers, specialty component suppliers, and others. These people look to ITER and TPX as real opportunities to learn, contribute and prepare for the future when the U. S. could be in a position to supply these systems to the world. The industry is developing. Today industry plays a complementary role to those scientific and technology experts and their programs being developed through the national laboratories. Tomorrow we hope to take on major roles in the design, construction and even operation of the experimental facilities previously mentioned. This is of course essential if shareholders of corporations are going to be willing to take the risk of constructing and warranting fusion power plants in the more distant future.

Finally, the utilities and IPPs have a role to play in all this. Today utilities are the owners and operators of essentially all nuclear fission electric generating plants. They bear the frustration mentioned earlier and the successes of efficient and economic operation when concerns over SO_x, NO_x and perhaps CO_2 are facing others. These same concerns and successes drive their desire to have power sources of small a size and complexity to insure regulatory approval and rapid introduction into useful use and consequent the rate base, - hence gas turbines and combined cycle units. Neither fission power plants or fusion power plants can be this simple - no matter how we argue their merits. Utilities or others will purchase and operate fusion power plants when they are available because they are cheaper, cleaner and safer than the alternatives at the time. They will be warranted by the industrial manufacturers for the same reasons. To say today that any fusion power plant is or is not acceptable is to anticipate a future that will be very different than it is today. Let us move on with the planned development of fusion power, find out what the economics of tokamak power plants will be, evaluate this for its environmental and resource utilization benefits and see what alternatives we have at that time to determine the commercial applicability of these systems.

Looking back on fission power only thirty years ago to the order for Oyster Creek in 1962 - the first commercial nuclear reactor - it was a very different time. Thirty to fifty years into the future, when fusion power has its first commercial order, will be an even greater difference. Let's move on with the development of fusion to see what the players will have to offer. Too many delays, changes or "what if's" today may make its availability over a hundred years off and it is not obvious that we can wait that long.

Mrs. LLOYD. Thank you very much, Dr. Forsen.

Mr. Walker, would you like to be recognized at this time? Your opening statement was included in the record.

Mr. WALKER. Well, thank you, Madam Chairman. If it was included in the record, I appreciate that. I did want to in the opening welcome Dr. Mills, who's going to be testifying later, to the Committee and appreciate your holding the hearing and all the witnesses appearing before us.

Thank you.

Mrs. LLOYD. Thank you very much.

Mr. Coppersmith, do you have any opening remarks?

Mr. COPPERSMITH. Just to thank you for holding the hearing and thanking the witnesses for appearing, and otherwise to get on with it. Thank you, Madam Chairman.

Mrs. LLOYD. Okay. As we look at the programs that we have worked with for the past two decades, we look at the mirror program, the inertial confinement, the Tokamak, and we've really come down to the Tokamak concept because we've, with the Fusion Advisory Board and the Department of Energy, have sort of agreed that this is the most likely candidate for full-scale commercial development.

And at this time there's a lot of talk now about alternative concepts, but do you feel that we should look at alternative technologies at this time in case we should have a problem or do you feel that we should continue with our mainline approach as we have envisioned not only in the Energy Policy Act, but by the Fusion Advisory Board? Or are we on track, Dr. Davies?

Dr. DAVIES. Madam Chairman, I believe we are on track. The thrust forward with the Tokamak is not a decision that we have made in a vacuum or even independently. The Europeans, the Japanese, the Russians are also pursuing fusion and some alternate concepts, but they also view the Tokamak as the concept that is ready to be taken forward and should be taken forward to an engineering test result——

Mrs. LLOYD. So, basically, there's international agreement——

Dr. DAVIES. Yes.

Mrs. LLOYD [continuing]. On the concepts that we've endorsed. Would you agree, Dr. Forsen?

Dr. FORSEN. I certainly would. I think it corroborates and confirms the decisions that have been made in this country that we can't do everything and that those things that yield to the development as we've tried to pursue them, which the tokamak has, suggests that we're on the right track.

Mrs. LLOYD. I know three years ago our Advisory Committee set up a review and established a policy to proceed. Is that pretty much in line with our Energy Policy Act of last year? Are the two policy acts pretty much in line?

Dr. DAVIES. Yes, Madam Chairman, they are very much in line. I would say that both the Fusion Policy Advisory Committee and the Energy Policy Act recognize inertial fusion as well as magnetic fusion as possible energy sources.

Mrs. LLOYD. But we're not——

Dr. DAVIES. It's very consistent.

Mrs. LLOYD. We're not funding the inertial program in the civilian budget, are we?

Dr. DAVIES. Very little.

Mrs. LLOYD. This is mainly our defense——

Dr. DAVIES. Right.

Mrs. LLOYD [continuing]. Programs as well?

I want to comment on tritium. It's my understanding that that is produced within the reactor and there's very little radioactivity to be concerned. Would you like to comment on that, Dr. Forsen?

Dr. FORSEN. Tritium is produced in the fusion reactor process by the capture of a neutron in lithium, and so the fuels for the fusion reactor really are deuterium and lithium, if you will. The tritium is contained within the reactor itself, recycled onsite, and used as the fuel.

Mrs. LLOYD. So that we don't have the problem of storage of waste or transporting fuels that—I want to ask you one other thing. We do have three major programs in our experimental Tokamak: the Tokamak and TFTR work, which we're concluding; Doublet at General Atomic; and Alcator at MIT. Are most of the— are these three reactors, are they—they're not duplicate efforts in any way, are they?

Dr. DAVIES. Madam Chairman, they are very distinct. Sometimes I think it takes a Tokamak aficionado to recognize the subtle differences, but they are very distinct and they're addressing different technical issues, all of them of importance to ITER.

Mrs. LLOYD. Thank you very much.

Mr. Fawell?

Mr. FAWELL. Thank you, Madam Chairman.

I do want to make it clear that you're not looking at a person who is against fusion. I know that it's long term, very, very long term, and so I suppose in many ways one can just criticize it on that basis, but I do not. I don't have a deep background on it, but, as I mentioned, in reading Dr. Hirsch's comments, I thought that at least as a type of a devil's advocate I could learn something and perhaps we all could be helpful.

Let me just repeat one of the comments where Dr. Hirsch observed that none of the very few fusion-knowledgeable utility people he had spoken with believed that the Tokamak or laser fusion reactors as currently envisioned would be acceptable to the electric utilities. And knowing, as a practical matter, that certainly you work closely, or should be working closely, with industry because they're the ultimate recipients of the benefits which will be forthcoming, and they're the ones who are on the front lines operating the facilities that produce electricity now, what would—how would you answer that? And, especially, I notice—let me just add, Dr. Forsen, you had said in your comments that industry applauds, for instance, building the TPX. So is there—is this inaccurate? Are you working closely with industry?

Dr. FORSEN. Industry in this sense are those people who ultimately will have to build and warranty those reactors, and I think in that sense the industry has come to understand fusion and it is participating. We think the TPX and ITER are both good opportunities for us. And, as I tried to indicate, because of the systems nature of fusion—that is, there are many parts, many subsystems, that industry can take responsibility for, I think when it comes to warranting that first-of-a-kind plan, you will have more than one industry involved. You will not just have, as we had in fission, a Westinghouse or a General Electric.

When it comes to the other part of your question about what the utilities might be interested in, I think we're faced today with a utility who tries to get in its operating base, as fast as it can, anything it wants to build, and so that's been gas turbines. And if you look at gas turbines, that's very simple to operate, but neither fission nor fusion will be as simple as that to operate.

Like, Dr. Davies commented that a 747 is not a simple system, we believe that fusion reactors, when fully developed, will be as reasonable to operate as anything that will be available at that time which will compete. If it isn't, we won't be building them; they won't be ordered.

But it's awfully hard today to look forward to 30, 40, or 50 years when fusion will be commercial and say what it will look like and what it's competition will be and whether something will be easier or harder to operate and how the utilities will be structured at that time.

So while Dr. Hirsch has some experience in this area, he's no better at looking at the future than any of us. We'll see what we can get when we get there, and I think we should get on with it and find out what fusion does have to offer.

Mr. FAWELL. All right. Well, what you're saying basically is industry then that is interested is not to any great degree the utilities or is that an incorrect conclusion?

Dr. FORSEN. The utilities' plate is pretty full today trying to operate what they have and their interfaces with the rate commissions and those problems. The industrial side, which is the manufacturers and warranters of systems, look at fusion as an opportunity, and we see that those systems are looking more complicated than other things we have done.

So if you couple what industry does—and today industry is operating power plants, I might add, and we do—I don't think we're necessarily overwhelmed by the difficulty of a fusion system. On the other hand, if you look at any experiment today, whether it's a fusion system or a cold fusion experiment with all of the leads and things coming out of it, if you're a utility executive, that scares you, and it scares you because you don't understand it.

Mr. FAWELL. Dr. Davies, from the viewpoint of the Department of Energy, I know that it is always a policy, I think, that you try to work as closely as possible with the utilities. Would you comment upon my questions?

Dr. DAVIES. Yes, I would. I agree with you, and I felt for some time that we needed to establish stronger ties with the utilities, probably through the Electric Power Research Institute, of which Dr. Hirsch is a representative.

And so even though the laws are changing and the regulations are changing, and it's not clear who's going to be building and operating the power plants in the future, I have felt that we have something to learn from the utilities today, especially the nuclear utilities who have experience in dealing with nuclear matters.

And so I have been trying to work with Dr. Hirsch, interacting with his fusion working group, and I've addressed the Research Advisory Committee of EPRI. And I would like to have people from EPRI and from utilities involved with us on our Advisory Committees and oversight groups that look at reactor studies and that sort of thing. And I hope that we can establish those ties. I know utility people who do believe you can commercialize fusion reactors. And so many utility people that I talk to just haven't particularly thought about fusion because it's so far away and, as Dr. Forsen says, they have so many near-term problems.

But we are trying to establish a working relationship with the utilities. We need to learn what they can teach us.

Mr. FAWELL. Yes, well, I think their interest would be helpful. And I thank you both for your comments.

Mrs. LLOYD. Thank you very much, Mr. Fawell.

Mr. Scott?

Mr. SCOTT. Thank you, Madam Chairman.

Dr. Forsen, did I understand you to say that there was no waste at all when we're dealing with fusion?

Dr. FORSEN. I didn't say that. Fusion does produce a neutron in the DT reaction. That neutrons makes things radioactive, not as radioactive as fission because there are no heavy actinide elements that come out of it, but fusion does have a radiation problem, yes.

Mr. SCOTT. How does that waste compare to the waste generated in the other nuclear reactors, the fission?

Dr. FORSEN. It is—the afterheat immediately after turning off a fusion reactor is comparable; it decays much faster than afterheat, radioactive heat, in a fission reactor. The waste that we envision for fusion reactors, if, in fact, low activation materials can be developed, and we work on that, will be considerably less. Even with the steels that we think of today, the radiation levels are considerably low.

The real advantage of fusion is that you do not have a fuel cycle and materials that you have to take out that are extremely hot, like the spent fission products in the fuel bundles of a fission reactor. That does not exist in fusion.

Mr. SCOTT. Dr. Davies, is waste, the disposal of waste, part of your jurisdiction?

Dr. DAVIES. For the Department as a whole, no, only in the planning for fusion.

Mr. SCOTT. OK.

Dr. DAVIES. I'm not sure—have I answered your question correctly or——

Mr. SCOTT. I guess I don't know. [Laughter.]

Dr. DAVIES. In planning—in looking at what the waste would be for fusion, that's part of my responsibility. But in today's world, the fusion program is not producing very much waste.

Mr. SCOTT. The Virginia Power and the Nuclear Shipyard have a proposal that's been floating around for a little while to have essentially canisters that could transport waste. Dr. Forsen, are you familiar with that proposal? Could you comment on it?

Dr. FORSEN. That's really fission reactor waste, which is high-level waste. Fusion reactors do not produce high-level waste as defined, and so this is a different problem.

Mr. SCOTT. So you don't need that level of protection?

Dr. FORSEN. But the problem is you've got to transport that ultimately to a repository some place; at least that's the plan for DOE. Currently, fission reactor waste is stored onsite in pools, letting it cool down because there's no place to take it. And those canisters are to help and hold that and move it, should that become——

Mr. SCOTT. And you wouldn't need that with fusion?

Dr. FORSEN. The fusion reactor materials, which is the basic part of the reactor, will become radioactive, but you don't carry those away every three months like you do in a fission reactor. In a fission reactor, about a third of the core—I shouldn't say every three months—a third of the core is replaced every year, and so you have this very high-level waste you've got to do something with.

Mr. SCOTT. OK. Dr. Davies, under the Energy Policy Act, there is a provision entitled "Disadvantaged Business Enterprises" that calls for agencies of DOE to provide 10 percent of their contracts to socially and economically disadvantaged small businesses and historically black colleges and universities. Can you tell me how you are implementing that now?

Dr. DAVIES. I may need to check and submit for the record exactly how we're responding to the provisions of the Energy Policy Act, but we do, through all of our contractors, have set asides for small businesses, small and disadvantaged businesses, and with historically black colleges and universities we have a major program that we carry out in conjunction with the Department's education program.

[The information follows:]

In Fiscal Year 1992 the Office of Fusion Energy obligated $1,021,000 for Historically Black Colleges and Universities and $270,000 for Small or Disadvantaged Businesses. In Fiscal Year 1993, $333,000 has been obligated and an additional $688,000 is planned for Historically Black Colleges and Universities. The current estimate is $274,000 for Small or Disadvantaged Businesses in Fiscal Year 1993. These total do not include subcontracts at the national laboratories.

Mr. SCOTT. Dr. Davies, DOE has focused its research efforts on the Tokamak South Facilities. Could you comment on the effect of concentrating on that one, possibly to the exclusion of others, will have on our ability to gain as much knowledge as possible?

Dr. DAVIES. Well, if we concentrate on the Tokamak, we will get more knowledge there than if we take some of those resources and put on other things. We believe we understand what we will get for our expenditures on the Tokamak. We don't know what we get or would get, could get, for our expenditures on innovation, alternate concepts, new proposals that have not been tested to a very high level yet.

And at the same time, because fusion is such a long-term program, people believe we should set aside some modest amount of funds for doing innovation. We should take a flyer and maybe something especially good will come out of it, and we're trying to do that.

Mr. SCOTT. Thank you.

Mrs. LLOYD. Thank you very much.

Mr. Barton?

Mr. BARTON. Thank you, Madam Chairman.

Dr. Davies, I should know this, but just for clarification, are you a Clinton appointee or are you one of the permanent staff at DOE?

Dr. DAVIES. I'm a career——

Mr. BARTON. Career?

Dr. DAVIES [continuing]. Person.

Mr. BARTON. And you've been involved with the fusion program for a number of years at the Department of Energy?

Dr. DAVIES. Yes. I came to the Atomic Energy Commission in 1974.

Mr. BARTON. Okay. How many billions of dollars have we spent on traditional fusion research; do you happen to know?

Dr. DAVIES. I don't. I can give it to you for the record. It must be about $8 billion.

Mr. BARTON. Eight billion. And are we anywhere near having a working fusion reactor; that is one that could self-sustain itself, self-sustain the reaction?

Dr. DAVIES. We believe that ITER will be self-sustaining, have an ignited plasma, and we're in the engineering design phase for that project right now.

Mr. BARTON. So within five years?

Dr. DAVIES. Oh, I expect it will be 2005 or so before it's built, partly because we're going to do it through international collaboration, and that takes a little bit longer. But we believe we have the scientific knowledge to do that today.

Mr. BARTON. Okay. I am just really intrigued by this White Paper that's going to come up later, this new fusion energy option. It talks about helium-3 and their request, I think, is for $100 million over five years. Is the reason that that's not being funded—I think there's $500,000 total in the proposed budget for alternative programs—is that purely and simply a factor of the monies all going to the traditional fusion program or are there some real scientific questions about this alternative in the research community?

Dr. DAVIES. That proposal or a scaled-down proposal responded to a Requests for Proposals we issued for small experiments, setting aside a million dollars this year, next, and the following year, with the idea that we would try to put more in depending on what the proposals were and how they were reviewed. But I believe a scaled-down version of that proposal was submitted and has been reviewed scientifically over the last couple of months. I don't quite have the results of the review yet.

There is one problem with helium-3. There isn't very much of it on the earth and it does not fuse with deuterium at the same rate as deuterium and tritium fuse. It's a couple of orders of magnitude less reactive. And so you have to have much better confinement in order to have the reaction rate go forward fast enough for you.

So those are always the two problems to consider when we talk about deuterium and helium-3. You have to have very, very good confinement and you have to have a source of helium-3.

Mr. BARTON. Well, I would hope—and, again, you know, I am an engineer but I'm by no means a fusion expert. So you're beginning to get out of my—you're probably way out of my range of competence already, but I would hope that better brains than mine in the Department of Energy would really seriously review this particular program because if it's half as good as the proponents make it out to be, I think it's well worth spending some research dollars to verify, because it at least on the surface appears, just on a cursory examination, to have tremendous potential.

I know your budget constraints are extremely tight, but I would hope that DOE might take a real look at that, and I certainly am very open to working with the rest of the Committee to see if we can't scrape together a few dollars from some other program, if that's the way it has to be, to fund this program.

I yield back. Thank you, Madam Chairman.

Mrs. LLOYD. Thank you, Mr. Barton.

Mr. Coppersmith?

Mr. COPPERSMITH. Thank you.

Dr. Davies, if the fusion budget does not increase, how likely is it that moving forward with the new Tokamak facility would result in the eventual exclusion of research on alternative fusion concepts?

Dr. DAVIES. I believe we are going to have difficulty moving ahead with the Tokamak concept if the fusion budget doesn't increase a little bit. One of the things that the Secretary of Energy Advisory Board looked at a year and a half ago was the fusion budget and the history of the program and where we were and what we needed, and their very strong recommendation to the Department was that the fusion budget ought to increase in real terms by about 5 percent, even if it had to come out of other Energy Research programs, because we were in danger of losing our ability to develop fusion.

Mr. COPPERSMITH. Dr. Forsen, I notice you were quoted in "Energy Daily" as saying that about 10 percent of the budget should be reserved for alternatives. Should the budget not increase in real terms, would that permit a reshuffling of priorities to do that? Is it important enough to do that? Or do you see the crowding-out happening?

Dr. FORSEN. I think it's very difficult if the budget maintains the level that it is now to carry forward with the international programs and domestic programs across the board. We have a real opportunity to make continued progress with the Tokamak.

And while I would support—and 10 percent is the number I did say; I didn't know it showed up in print, though—part of that 10 percent really ought to go to making the Tokamak better, too.

Mr. COPPERSMITH. That's something we learned; I just want to devote that to you: that you never know when something you say ends up in print. [Laughter.]

Dr. FORSEN. I'm learning.

But 10 percent is a reasonable number in—I don't want to call it—a robust program, because we don't have a robust program. We have sort of a minimum program that's making progress to getting us there.

If you continue to try to support the things that the Committee has asked about broadly and the budget stays where it is, we will not be able to participate in the things that we're committed to.

Mr. COPPERSMITH. Dr. Forsen, I just want to follow up on some of Representative Scott's questions, just to get some sort of sense. Could you be more specific as to what types of waste would be produced by fusion, particularly through a Tokamak reactor? And then how much waste would be produced and how would it be disposed of?

Dr. FORSEN. I'm sorry that Mr. Barton is not here because I did want to comment on his question, too.

Mr. COPPERSMITH. Oh, go ahead. He'll read it.

Dr. FORSEN. In any reaction where you're using deuterium, whether it's deuterium/tritium or deuterium/helium-3, as long as deuterium's in there, neutrons will be present because there are DD reactions which take place. Those neutrons will activate the materials around them, and in the case of a deuterium/tritium reaction, those neutrons are very abundant.

The reactivity of the materials, current materials, the nonferrous materials, is such that those materials have a problem of how long will they live; mainly, can you keep the wall-loading down to the point where the reactivity, where the physical properties of those materials last long enough? And, clearly, early concepts even took into account the possibility of having to replace those materials every once-in-a-while, as suggested that Dr. Hirsch had mentioned.

Mr. COPPERSMITH. Those are the thermal shields you're talking about here?

Dr. FORSEN. That's the vacuum shield. It has to go through the vacuum shield into a blanket where that neutron is captured in lithium, which makes the tritium.

All those neutrons are captured, and as they go through materials, they activate them in one sense or another. Our hope is—and that's why we want a materials program, why we need a neutron source for those materials, to try and make low activation materials, materials of low Z, low charge numbers, such that their activation will be considerably less. Again, it's the hope that the level of activity of materials that have to be gotten rid of in the fusion system will be possible, will be able to be handled as low-level waste, just as we do gloves and other things today.

If we can't get there, it will just be, you know, orders of magnitude better than fission reactors because it's just not that hot. But as long as you have neutrons, you're going to have radiation.

Mr. COPPERSMITH. We don't really have a good sense of what types of quantities we're talking about and——

Dr. FORSEN. In terms of tons per megawatt produced, no, we don't, but I'm sure somebody does; I do not.

Mr. COPPERSMITH. All right. Finally, Dr. Davies, I believe last year $350 million was appropriated for the program. How much of that went to ITER research and development?

Dr. DAVIES. In this year, $52 million is going to ITER, and we're planning $64.5 million next year.

Mr. COPPERSMITH. And how much of the $340 million in the current Fiscal Year was spent on Tokamak research reactor development, research and development generally?

Dr. DAVIES. Oh, it must be about $180 million.

One hundred fifty-six million is being spent directly on the major tokamak physics experiments in Fiscal Year 1993. The entire fusion budget, except for about $17 million in the non-tokamak magnetic fusion concepts and inertial fusion energy, supports the development of the tokamak concept.

Mr. COPPERSMITH. Thank you.

Mrs. LLOYD. Thank you, Mr. Coppersmith.

Mr. Walker?

Mr. WALKER. Thank you, Madam Chairman.

Dr. Davies, did I hear you say a few minutes ago, in answer to another question, that $8 billion had been spent on fusion?

Dr. DAVIES. I believe that's about right.

Dr. WALKER. Does that include defense? Does that include the defense?

Dr. DAVIES. No, sir, that would be magnetic fusion only.

Mr. WALKER. So if we took the two together, the figure I had heard was around $15 billion. Is that—is that——

Dr. DAVIES. That sounds a little bit high because over the years inertial fusion has been funded at a lower level than magnetic fusion.

Mr. WALKER. OK.

Dr. DAVIES. One-third and two-thirds.

Mr. WALKER. I must say that the frustration that I feel—and this has been expressed before—as someone who's been on this committee now for 17 years, I remember coming here as a relatively naive member and listening to some of these hearings and being told at that time that we were 10 years away from success back in the late seventies, and the timeline always seems to be 10 years. Now I must admit that today we're maybe becoming a little more honest. It sounds to me more like 20 years today.

I heard you say a minute ago that we now think we know the science necessary to achieve this end. So do I understand that after spending $8 billion, we know the science, but we still haven't spent enough money to do it right? Is that kind of the way we are?

Dr. DAVIES. I would probably put it a little differently. [Laughter.]

We understand enough of the fundamental science of tokamaks to understand how to design one that will be self-sustaining. We're also learning enough science to understand how we can make a better reactor in the long term out of the tokamak. We have learned a lot of science. We've also developed a fair amount of technology over this time that would be applicable to fusion.

The money that we have spent in the United States is probably comparable to what has been spent in the European Community. Japan probably has spent less. Japan is spending as much as we are today. The European Community is spending approximately twice what we are spending on fusion, on magnetic fusion.

Mr. WALKER. Haven't the Brits had a successful experiment in the last year or so?

Dr. DAVIES. You're probably thinking about the Joint European Torus which is located in the United Kingdom.

Mr. WALKER. Correct.

Dr. DAVIES. It's actually—it's a Euratom experiment. It's a joint experiment. Yes, very successful.

Mr. WALKER. And what has been their relative investment compared to ours?

Dr. DAVIES. In comparison to the Tokamak Fusion Test Reactor, I don't remember the multiplier, but it's considerably more than we have spent on our experiment at Princeton, considerably more.

Mr. WALKER. And the alternative monies that you're hoping to include in the budget for this year, we've had a little bit of discussion here about it. Could you give me some idea as to what some of those alternatives were that I heard you discuss a minute ago, that the helium-3 experiment is one that you've looked at? Could you give me some idea of some of the others that might be potentially fundable under an alternative budget?

Dr. DAVIES. We did a very open solicitation and asked for improvements to the tokamak or any other clever idea that could extrapolate to an attractive magnetic fusion reactor. And there were a number of things that people have considered over the years or have thought of more recently that were proposed.

In addition, too, there were colliding beams, there were ion rings, there were dense Z pinches, also electrostatic confinement schemes concepts that were proposed.

Mr. WALKER. Well, I don't know exactly how to ask the question. I'm wondering how you're going to get that by the community that I have always found as one of the most resistant communities to new ideas that I've come across in this business. If we put money in for alternatives, how are you going to get the community to really respond to some of the new concepts that might, in fact, get in the way of 20 years of experimentation that has basically gone on along a single track?

Dr. DAVIES. Well, we did bring in people from labs and universities to review these concepts, these proposals. Fusion scientists get very excited about new scientific ideas. That is my experience. I don't think any of them feel threatened by small-scale experiments at this point.

Mr. WALKER. Well, what I have found, though. they feel threatened the moment somebody suggests that there's some new idea that might begin to shift money in the various programs. At that point, then, there's a good deal of excitement that seems to be generated. And, as a result, the tendency has been not to put very much validity to any kind of new concept that might sound like it is going to have the potential of shifting money. So, therefore, the analysis that you get from people within the community is limited by what they think is in their long-term interests.

Dr. DAVIES. Well, in the history of the fusion program in the United States, we have put large amounts of money into non-tokamak concepts, and over the years we have reviewed and funded probably 20 different concepts over the two decades. We have put large amounts of money in non-tokamak work, and some of it has not panned out and some of it has failed for other reasons, but we have put large amounts of money into other things.

Mr. WALKER. Well, but have most of those been, though, aimed at magnetic fusion concepts?

Dr. DAVIES. Yes, but a lot of them were quite different from the tokamak.

Mr. WALKER. Yes, but, basically, what I'm talking about is, What if somebody comes along with something that's kind of a non-magnetic fusion concept? What if somebody comes along with a fairly brand-new idea. It's then when I think that the resistance seems to develop in fairly—on a fairly wide basis.

Dr. DAVIES. Well, your basis is that the tokamak people would feel threatened because their budgets would be shifted, but in the past money has been shifted out of the tokamak program into other magnetic concepts. Tokamak people have been involved in the peer review, and they've been able to be scientific about it.

Mr. WALKER. Well, I guess I'm being, to use the word that's becoming increasingly popular on Capitol Hill, I'm being more global than that. My concern is that, you know, that all of those people are kind of in the same boat, so to speak. I mean, as long as it's magnetic fusion, that's fine. You know, it may not be the tokamak that they're working on, but at least we're not getting outside the area that's kind of the accepted realm, and, therefore, new concepts are accepted as long as they are narrowly within that, as long as they're small-scale enough that they don't appear to be too threatening.

But the moment that somebody comes along with something that sounds like it's in a different realm, that's when I—that's, at least in my impression, when we get an awful lot of controversy that then arises. And I'm wondering what the Department is doing essentially to assure that there are going to be alternatives.

My guess is, as we develop better information, as we develop computer technology that allow us to do better analytical capability, as we have all of these new opportunities available to us, that we're going to get lots of people out there with lots of ideas that will be nontraditional in nature. Some of them may be lousy ideas and they may have no merit whatsoever. One or two of them may be the breakthrough that defines the future. My concern is that we have in alternative programs an ability to analyze and decide when we've got something that may define the future.

Dr. DAVIES. I understand your concern, and what we try to do in these circumstances is be sure that what people are dealing with are the technical issues, actually dealing with the physics, with accepted theories, accepted computations, accepted experimental results. So that these judgments are based—our decisions are based on sound technical assessment of proposals or of results of experiments.

I would give you one final example, and that is that the magnetic fusion community, with people from the inertial confinement program, just reviewed our heavy ion accelerator program, and that's quite different from anything we've ever done in the magnetic fusion program. And they gave it a very strong vote of confidence, technical confidence. They spent months reviewing it.

Mr. WALKER. OK, thank you, Madam Chairman.

Mrs. LLOYD. Thank you, Mr. Walker.

Mr. Klein?

Mr. KLEIN. Madam Chair, in the interest of proceeding along with the hearing, I will waive any questions of this panel.

Mrs. LLOYD. Thank you very much, Mr. Klein.

I do want to compliment our new members and your level of attendance, your participation. We are very lucky to have good new members as well as old members on our committee. [Laughter.]

I'd like to followup on Mr. Walker's question just for one minute because I think we're really portraying the dilemma of our fusion program, because you're right, Dr. Davies, we have funded other technologies, but then we come along where we've spent $30 billion while we stretch out, while we try to take care and accommodate other programs.

Now I'm not sitting here just saying we should not look at alternative technologies. I'm not saying that. I'm not saying we should, but I am saying this committee should very closely look at the guidance that we're giving you in your Department, because if we're going to say, you hurry up, do this as quickly as you possibly can, we're sorry that we haven't moved on it any faster than we have—but we can't have it both ways. We can't tell you to maximize your efforts and at the same time tell you to continue to look at every technology that comes along, because I don't think you can do that. And I think that's the dilemma that we have that we want to cut back on the programs, but at the same time we have to look at what is—what we can, in our judgment, decide is the best technology, the best way to spend our money to maximize our return in the quickest possible time.

And you've got a big job and you've got a tough job, and I want to commend the fusion community for your efforts. Thank you very much.

Our next panel looks at our Tokamak programs: Dr. Paul-Henri Rebut—did I get that right, Rebut; I hope I did?—who is Director of our International Thermonuclear Experimental Reactor, our ITER reactor, at La Jolla.

Then we have Dr. Charles Baker, who is our U.S. Home Team Leader on the ITER program, who is from Oak Ridge, Tennessee. And I'm awfully glad to see you today.

And then, of course, Dr. Ron Davidson is director of Princeton Plasma Physics Laboratory, and we're glad to see you as well.

Please proceed, Dr. Rebut.

STATEMENT OF DR. PAUL-HENRI REBUT, DIRECTOR, INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR, SAN DIEGO CO-CENTER, LA JOLLA, CA; ACCOMPANIED BY DR. CHARLES C. BAKER, INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR, U.S. HOME TEAM LEADER, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN; AND DR. RONALD C. DAVIDSON, DIRECTOR, PRINCETON PLASMA PHYSICS LABORATORY, PRINCETON, NJ

Dr. REBUT. I would like to start by a remark which is simply to say that the annual cost to develop a fusion reactor will amount to approximately between .1 and .2 percent of the electricity power cost incurred annually by countries of the OECD.

Now I would like to concentrate, first, on what I consider is the success of the physics phase in fusion. Since the mid-seventies, a 1000-fold increase has been achieved in the overall performance of experimental fusion devices. We are now within a factor of five of the fusion performance required for a fusion reactor. This factor will be gained by an increase in the size of the plasma.

On November 9, 1991, a deuterium/tritium fuel mixture, including only 10 percent of tritium, introduced in JET, Joint European Torus, produced over a megawatt of fusion power for more than two seconds. I believed for us when we started—and I have started in 1958 in this field—this will have been the demonstration that physics of fusions is controlled.

So having effectively demonstrated the scientific feasibility, the subsequent development stages leading to fusion power stations can now be defined. And we can now focus our effort on the fusion reactor. In fact, the International Thermonuclear Experimental Reactor, ITER, is the core of a power reactor.

U.S., Europe, Japan, and Russia have signed the ITER Engineering Design Activity Agreement on the 21st of July 1992.

The ITER device is foreseen to be the first experimental reactor and will be able to produce high grade heat from controlled fusion reactions well over 1 billion watts. It will also test the major new technologies required for a fusion power station taking account of environmental aspects.

As the ITER Director, I am committed to see ITER built, but, for me, the real goal is not any one specific device, however important, but the establishment of fusion as a major source of energy. ITER should, therefore, be seen as the leading element of a balanced fusion reactor development program. To that end, ITER must be built, but at the same time there should be a complementary program providing, for example, an intense neutron source to test materials; new and innovative development of a different device; continued study of the detailed physics of fusions; and, also, the education and training of a new generation of scientists and engineers required to carry the program forward.

Such an overall fusion reactor development program is required. Undertaken on an international basis, it will allow a balanced approach for all parties concerned, be cost-effective, but it is also a managerial, political, and industrial challenge.

The philosophy of ITER is to design a machine on the basis of experience acquired with present machines such as JET and DIII-D. It also incorporates the following principles: design simplicity, as much, of course, as we can; flexibility of the machine; reliability and quality—I believe this is quite important, to have it working properly—safety; and reactor relevance. But this machine must incorporate, whenever possible, technologies that are relevant to a fusion power reactor.

Since the signature of the ITER EDA Agreement, progress has been rapid. This has been achieved with the strong support from members of the international fusion community, among which I can particularly commend the U.S. fusion community for its commitment. It is also the result of having a well-defined objective focusing the fusion community toward a common goal.

ITER is now the leading element of the world fusion program. ITER will incorporate very advanced technologies and materials and cannot be built without the full participation of industry. In that sense, ITER should prove invaluable in developing some technologies with wide potential applications in modern science and industry, such as advanced materials and superconducting technologies. I see U.S. industry as a cornerstone of these activities.

Strong participation and leadership by the U.S. in the ITER project is fundamental to the success of this novel venture. An early site decision for the construction of ITER is needed to complete the EDA according to schedule. If a site can be selected within three years, construction could start at the end of the engineering design activity in 1998.

The final results of the engineering design activity will be made available for each of the parties to use as part of an international collaborative program or in its own domestic program. I believe that the U.S. is uniquely placed to play a leading role in progressing toward the construction of ITER. I should like to encourage the U.S. Government to pursue with its partners an early agreement on the site and the creation of the legal structure for the construction of this unprecedented international project.

With the commitment and the leadership of the U.S., I am confident that ITER will be built and will fulfill its objectives.

I thank you, Madam Chairman and members of the subcommittee, for inviting me to testify. I would like also to invite all of you to visit us at San Diego at the Joint Work Site, but today I shall be pleased to answer any questions that you may have for me.

[The prepared statement of Dr. Rebut follows:]

TESTIMONY OF
PAUL-HENRI REBUT
DIRECTOR
INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR
BEFORE THE
SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
MAY 5, 1993

Madam Chairman and Members of the Subcommittee on Energy, I am grateful for this opportunity to testify before the U.S. Congress on the progress in Fusion towards an Experimental Reactor.

Thermonuclear Fusion offers the prospect of having an inexhaustible and environmentally acceptable energy source available as the world's population increases and living standards in the developing nations improve. Fusion could make a significant contribution to energy production from the middle of the 21st century comparable to other energy sources. Once the technology is developed there should be enough fuel on Earth to meet mankind's energy requirements indefinitely.

The annual cost to develop a fusion reactor would amount to approximately 0.1% of the electric power costs incurred annually by countries of the OECD [Organization for Economic Cooperation and Development]. This is a small investment for the capability to produce electricity necessary to sustain the long-term development of the world economy.

SUCCESS OF THE PHYSICS PHASE IN FUSION

In recent years the progress in fusion energy research has been most impressive. Since the mid-Seventies a 1000-fold increase has been achieved in the overall performance of experimental fusion devices. We are now within a factor of five of the fusion performance required for a fusion reactor. This factor will be gained by an increase in the size of the plasma. On November 9th 1991, a deuterium-tritium fuel mixture introduced in the JET [Joint European Torus] device produced over a million watts of fusion power for more than two seconds. These achievements are the result of the determined pursuit of strong and focused programs with involvement of industry.

Having effectively demonstrated the scientific feasibility, the subsequent development stages leading to fusion power stations can now be defined. Drawing on experimental results from JET and from the other major devices in the US, Europe, Japan and Russia we are able to define a fusion reactor.

TOWARDS A FUSION REACTOR

As we have demonstrated that we can control the kind of plasma required for thermonuclear reactions, now we have to focus our effort on the Fusion reactor. In fact, the International Thermonuclear Experimental Reactor, ITER, is the core of a power reactor.

With the signing of the ITER Engineering Design Activity Agreement on 21 July 1992 the world fusion community as a whole is engaging on the path towards a fusion reactor.

The ITER device is foreseen to be the first experimental reactor and will be able to produce high grade heat from controlled fusion reactions well over one billion watts. It will also test the major new technologies required for a fusion power station taking account of environmental aspects.

By its existence, the ITER EDA project is already focusing the fusion programs of the world. As ITER Director, I am committed to seeing ITER built. **But, for me, the real goal is not any one specific device, however important, but the establishment of Fusion as a major source of energy.** ITER should therefore be seen as the leading element of a balanced Fusion Reactor Development Program. To that end, ITER must be built but, at the same time, there should be a complementary program providing, for example:

- an intense neutron source to test the durability of materials;
- continued development of new and innovative aspects of the reactor;
- continued study of the detailed physics of fusion power; and
- the education and training of a new generation of scientists and engineers required to carry the program forward.

Such an overall Fusion Reactor Development Program is required. Undertaken on an international basis, it would allow a balanced approach for all parties concerned, be cost-effective and be practical in managerial, political, and industrial terms.

ITER

The philosophy of ITER is to design on the basis of experience acquired with present machines such as JET and DIII-D. It also incorporates the following principles:

- design simplicity — to ease manufacturing and thereby effectively reduce costs;
- flexibility — to accommodate the evolution of fusion science that will occur during its operating life time;
- reliability and quality — to ensure operation of key components without fault for decades;
- safety — to demonstrate the potential of fusion as an environmentally attractive source of energy; and
- reactor relevance — incorporation, wherever possible, of technologies that are relevant to a Demonstration Reactor.

Since the signature of the ITER EDA agreement, progress has been rapid with the preliminary design being presented just seven months after the start of assembly of the core Joint Central Team (See Attachment). This achievement was only possible with the strong support from members of the international fusion community among which I can particularly commend the US fusion community for its commitment. It is also the result of having a well-defined objective focusing the fusion community towards a common goal.

ITER is now the leading element of the world fusion programs and is creating a dynamic movement from which new ideas and solutions are continually emerging and evolving. From this process, key areas of technology R&D are being addressed, using the competence of the Parties' industries and fusion laboratories. ITER will incorporate very advanced technologies and cannot be built without full participation of industry. In that sense, ITER should prove invaluable in developing some technologies with wide potential application in modern science and industry, for example, advanced materials and superconducting technologies. I see US industry as a cornerstone of these activities.

THE US — A LEADING PARTNER

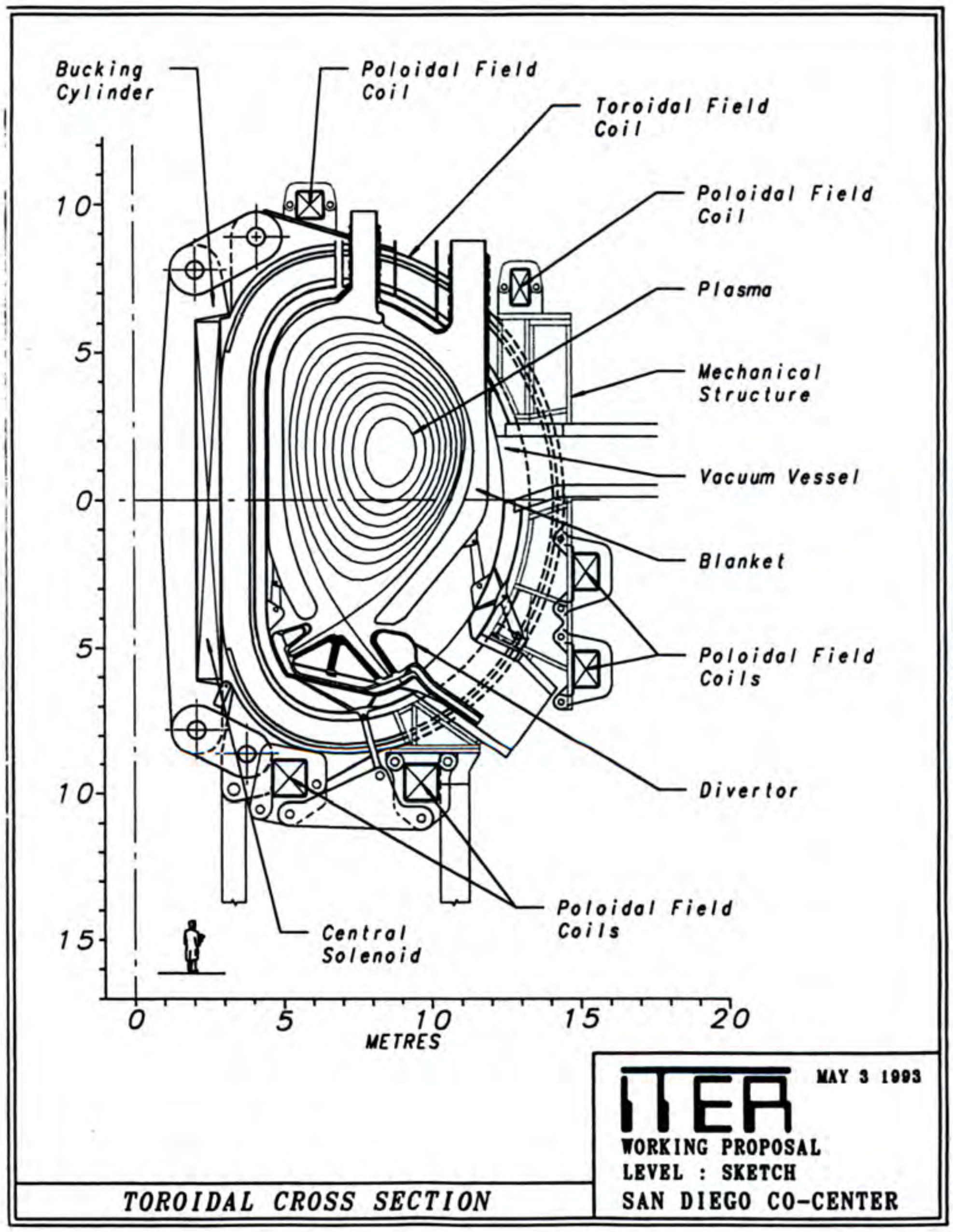
Strong participation and leadership by the US in the ITER project is fundamental to the success of this novel venture. An early site decision for the construction of ITER is needed to complete the EDA according to schedule as many of the site characteristics must be incorporated into its final design. If a site can be selected within three years, construction could start at the end of the EDA in 1998.

The final results of the Engineering Design Activities will be made available for each of the Parties to use as part of an international collaborative program or in its own domestic program. I believe that the US is uniquely placed to play a leading role in progressing towards the construction of ITER. I should like to encourage the US Government to pursue with its partners an early agreement on a site and the creation of the legal structure for the construction of this unprecedented international project.

The challenge facing the world today is to develop a solution for an economical and environmentally attractive large-scale energy source for the benefit of mankind. I believe that fusion will enter into that solution — ITER being a major milestone in this process.

With the commitment and leadership of the US, I am confident that ITER will be built and fulfill its objectives.

I thank you, Madam Chairman and Members of the Subcommittee, for inviting me to testify. I invite all of you to visit the Joint Work Site at San Diego, but today I shall be pleased to answer any questions that you may have for me.


Bucking Cylinder
Poloidal Field Coil
Toroidal Field Coil
Poloidal Field Coil
Plasma
Mechanical Structure
Vacuum Vessel
Blanket
Poloidal Field Coils
Divertor
Poloidal Field Coils
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METRES
ITER
MAY 3 1993
WORKING PROPOSAL
LEVEL : SKETCH
SAN DIEGO CO-CENTER
TOROIDAL CROSS SECTION

Mrs. LLOYD. Well, thank you very much, and we know you were here last week and didn't get to testify. We appreciate you coming back today, and we'd certainly like to visit you as well.

And, Dr. Baker, please proceed.

Dr. CHARLES BAKER. Thank you, Madam Chairman, members of the Subcommittee. I'm very happy to have this opportunity to testify before you. I've prepared a written statement, and I've also included a copy of an ITER booklet that I'd like to include with that statement, if I may.

Mrs. LLOYD. And it will be made a part of the record.

Dr. CHARLES BAKER. I appear before you today mainly in my role as leader of the United States Home Team for ITER, but I'm also an associate director of the Fusion Energy Division at the Oak Ridge National Laboratory. And, Madam Chairman, let me say that the dogwoods were a little late this year, but absolutely gorgeous. I hope you had a chance to come back home.

Mrs. LLOYD. Well, I think you know that I'm there about every weekend. I was in Oak Ridge last weekend.

Dr. CHARLES BAKER. I would like to make a couple of personal comments about the significance of ITER, if I may. What does ITER mean and what is its significance?

We are about to undertake a serious effort to design an actual fusion reactor for the first time. If ITER is built, which we all hope, it will essentially be a complete model of the core of an operating fusion reactor. It's not an overstatement to say that I think that we're entering a new era, but certainly you and members of this committee who have followed fusion over the years understand what a challenge and how hard this task is, and we are about to do it.

For those of us who have committed our professional careers to this, it's a culmination we have looked forward to for a long time, and we are quite excited about it and very pleased to be part of this process.

I'm happy to report that ITER is going very well, certainly at the international level, under the capable leadership of Dr. Rebut, who is one of the most outstanding leaders in the world fusion community, and we're very fortunate that he's willing to take on what is a most demanding job. He must invite you to come to San Diego, but I suspect he's not there very much, as he travels literally around the world on almost a constant basis.

The mission that ITER meets in our program is that of what's generally called an engineering test reactor. It represents the time in which we will actually construct the components of a real fusion reactor and find out how to assemble them and make them work. This central mission is common to the strategy of all the countries involved in fusion. It's a central feature in the United States strategy, in Japan, Europe, and in Russia.

Because it fits this central mission, it is the main reason that we have been able to come together at the international level and form this agreement to work together. During this phase of the engineering design activities, the United States plans to spend about $450 million, a considerable amount of money. The other parties will spend equal amounts. And from that will emerge an engineering design to allow us to make a decision to construct that first fusion reactor. As Dr. Davies said, the budget request for Fiscal Year 1994 for ITER is $64.5 million, and I support that. It will allow us to meet our international commitments.

The international team is forming. We in the United States will have 30 people on site here in San Diego, in Germany, and in Japan, some 40 people near the first part of the next Fiscal Year. Back home, our home team is truly a national effort, quite literally spread across the United States. We have eight national laboratories, ten universities, and now nine industries, and they are growing. We have made a special effort this past year to increase the industrial participation in the ITER program. And, as Dr. Forsen told you earlier, he chairs a council which advises me on the policy question of how to increase American industrial participation in ITER.

Let me briefly note these companies that are now a part of the U.S. Home Team. They include companies such as Ebasco, General Atomics, General Dynamics, Grumman, McDonnell Douglas, Pitt Des Moines, Rockwell International, Westinghouse, and we're about to add another part of our team which will include many of these people, which will include companies like Chicago Bridge and Iron, Science Applications International, Stone and Webster, and TRW.

I think you will agree that represents a truly powerful cross section of American industry, which now, combined with our universities and laboratories, gives us a very strong home team. We are carrying out a broad set of activities this year, covering the full range of work from physics analysis, engineering studies, systems evaluation, and technology development. And the activities this year are funded at the level of $52 million.

There's one aspect of this that I would like to make particular mention of, if I may. It is important that the site be selected for ITER sometime before the end of this engineering design activities. And the reason is that some of the engineering work will be site-specific.

We should be able to identify that site within two or three years from now, and that's a very difficult technical and political challenge, and you all know a lot more about the latter part than I will. I congratulate the Congress for the leadership you've shown in urging that this be undertaken and urge the Congress and the Department of Energy to get on with this as soon as possible.

The U.S. needs a new fusion site. We're entering a new era. None of the existing fusion laboratories have the capabilities to house the major facilities that are required in the future. This new U.S. fusion site could host ITER if, in fact, we win at the international level. But there are other major facilities for a potential new site as well, such as a high-energy, high-flux neutron source for materials development, and concepts that are called volume neutron sources for technology development and the like.

I think it's important to recognize this because if we're going to have a successful decision at the international level, we probably will have to work out some kind of equation that has more than one facility to place around the world. Of course, ITER is the flagship, but it's not the only facility.

Finally, in conclusion, I would just like to reiterate that ITER is proceeding well at both the international level and with the U.S. Home Team. Our home team is organized. We substantially expanded industrial participation, and we are committed to having that grow in the future. This increased industrial participation will help prepare American industry to compete successfully for the construction of ITER. It will substantially increase the technology transfer process from the laboratories to industry, and I think it will be an important step of generally increasing the international competitiveness of American industry.

I would urge again early attention to the site selection issue. And let me finally note that ITER is not only a major technological change, but it is breaking ground every day teaching us how to work together. And, as I know my colleague, Dr. Rebut and I can attest, we're learning this day by day literally around the world. It is quite literally true that ITER work goes on 24 hours a day, and my fax machine at Oak Ridge can attest to that fact on any given day.

I appreciate the opportunity to make these comments and I would be happy to answer questions.

[The prepared statement of Dr. Baker follows:]

Statement of Charles C. Baker

U.S. Home Team Leader

International Thermonuclear Experimental Reactor (ITER)

and

Associate Director

Fusion Energy Division

Oak Ridge National Laboratory*

Operated by Martin Marietta Energy Systems

for the Department of Energy

Oak Ridge, Tennessee

Before the

Subcommittee on Energy

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

May 5, 1993

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*Oak Ridge National Laboratory managed for the U.S. Department of Energy by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400.

**CONGRESSIONAL HEARINGS
ON
FUSION ENERGY CONCEPTS
MAY 5, 1993**

**DR. CHARLES C. BAKER
OAK RIDGE NATIONAL LABORATORY**

Madam Chairman and Members of the Subcommittee, I am very pleased to have the opportunity to testify on the magnetic fusion energy program. I appear today mainly in my role as U.S. Home Team Leader for the International Thermonuclear Experimental Reactor or ITER Project. I am also Associate Director of the Fusion Energy Division of the Oak Ridge National Laboratory.

Madam Chairman, I have included a copy of an ITER booklet which I would like to submit with my written testimony.

I support the Department of Energy's request for $347.6M for the Magnetic Fusion Program for FY 1994. In particular, the request for ITER activities of $64.5M will allow the United States to meet its international commitments. I am happy to report that ITER is progressing well at both the international and domestic level.

The goal of ITER is to demonstrate the scientific and technological feasibility of fusion energy. It will do this by demonstrating controlled ignition, extended burns in deuterium-tritium plasmas, integration of technologies essential to reactors and testing of components for the utilization of fusion energy. ITER meets the mission needs of an engineering test reactor.

This mission plays a central role in the development strategies of all the other key nations involved in fusion energy R&D. It is the reason that the ITER Parties – European Atomic Energy Community, Japan, Russian Federation, and the United States – have agreed to undertake the current phase of ITER, which is called the Engineering Design Activities (EDA). This activity began officially on July 21, 1992, with the formal signing of the agreement here in Washington. It will last six years and will be followed, if the Parties agree, by a seven-year construction phase. Present plans aim to begin operation of ITER in the year 2005.

U.S. ITER expenditures during this six-year phase are estimated at about $450M. Similar expenditures will be made by each of the other three Parties.

We are very fortunate to have Dr. Paul-Henri Rebut as the Director of the ITER Project. Dr. Rebut assumes this challenging position after many successful years as the Director of the Joint European Torus (JET) program. As the ITER Director, Dr. Rebut is supported by a core team of scientists and engineers drawn equally from the four Parties.

The core team, called the Joint Central Team, operates from three ITER Co-Centers located at Garching, Germany; Naka, Japan; and San Diego in the United States. Each Co-Center is under the direction of a Deputy Director. The Head of the Garching Co-Center, Dr. Ronald Parker, is from the United States.

The process of staffing the Joint Central Team by the four Parties began soon after the Director was appointed last September and continues today. The goal is to complete this staffing process by March 1994. Three individuals from the United States were selected to important senior level positions, called Division Leaders, at the three Co-Centers. These include division level positions responsible for the magnets at the Naka Co-Center, for design integration at the San Diego Co-Center, and for the overall plant engineering, also at San Diego. We expect to have approximately 30 individuals from the U.S. as members of the Joint Central Team by the end of this fiscal year. This will increase to approximately 40 next year, which will fulfill the United States obligation to provide one quarter of the professional staff for the Joint Central Team, which has currently been set at 150 professionals.

Let me indicate how we are organized within the United States. The United States efforts on ITER are conducted nationwide involving many institutions. Collectively, these institutions constitute the U.S. Home Team in the ITER program. These institutions include nine national laboratories, ten universities, and at least nine industries. (Please see list at the end of my testimony). Our project office is hosted by the Oak Ridge National Laboratory.

During the past year, we have established contracts with industrial firms competitively selected to participate in the ITER program. These firms will participate as partners with the national laboratories and universities in our program. They have an impressive breadth and depth in engineering capability and technological experience. The industries include CIMCORP Precision Systems, Inc.; Ebasco Services, Inc.; General Atomics; General Dynamics; Grumman Aerospace Company; McDonnell Douglas Aerospace; Pitt Des Moines, Inc.; Rockwell International; and Westinghouse Electric Corporation. We also have some small businesses participating in ITER through the SBIR program.

The industries are working on assigned design and research and development tasks in five major areas. These areas are: (1) superconducting magnets; (2) components which immediately surround the hot, burning plasma, such as the first wall and the divertor which is used to provide exhaust of the plasma; (3) components designed to absorb the plasma energy and transport the deposited heat away from the plasma such as shielding components and components to breed tritium fuel; (4) equipment needed for remote maintenance, assembly, and disassembly; and (5) components associated with the vacuum vessel which provides the vacuum boundary for the plasma. In addition to industry support in these areas, we are in the final stage of selecting industry to provide design and design integration support. We are pleased that we have added this industrial capacity to our Home Team. We are excited about the prospect of molding partnerships between our strengths in the national laboratories and universities with the strengths of these industries.

Within the U.S. Home Team organization, we have two advisory committees which provide counsel to me. The first is the ITER Steering Committee - U.S., or ISCUS, which is comprised of senior experts from the major fusion research laboratories and universities in the United States. This committee provides technical and programmatic advice on a broad range of issues, and is chaired by Prof. Weston Stacey of the Georgia Institute of Technology.

The second committee is the United States ITER Industry Council, which is comprised of senior management from energy-related industry firms. The committee provides advice on the full range of issues related to industry participation in ITER. The Industry Council is chaired by Dr. Harold Forsen of the Bechtel Corporation.

As the U.S. Home Team Leader, I have two primary responsibilities. I am responsible to the Director for executing ITER tasks assigned to the United States. In addition, I am responsible to the Department of Energy and the Office of Fusion Energy for planning and integrating the efforts of the U.S. Home Team. I believe that, together, we have developed a strong working relationship between the Office of Fusion Energy and the U.S. Home Team.

Our technical work in the past year has been in a number of broad areas. These areas include design, analyses, and research and development activities required for ITER to be successful. The design of the ITER tokamak is making good progress. ITER will produce 1500 to 3000 megawatts of fusion thermal energy. The plasma will be confined by magnetic fields up to 13 Tesla and plasma currents of 25 million amperes. ITER constitutes, in essence, a complete "fusion reactor core."

The United States is making major contributions to the physics understanding necessary for the confident design of ITER. These contributions are coming from experiments at major U.S. research facilities (TFTR, DIII-D, Alcator C-Mod, PBX-M, and TEXT-U), and from programs at a number of other laboratories and universities. The U.S. program in the physics area is focused on resolving key issues for ITER including plasma confinement, plasma equilibrium and stability, the behavior of alpha-particles, how to handle the considerable power coming from the plasma, and how to heat the plasma to operating temperatures.

We have major technology programs underway in several areas, including superconducting magnets; plasma facing components such as the divertor and first wall; blankets and shielding; fueling; tritium systems; remote handling systems; vacuum vessels; heating and current drive systems; diagnostics; and safety and environment systems. Increasingly, this work is being performed in close cooperation with the Joint Central Team.

We are performing engineering design and analyses on essentially all of the tokamak systems and components in close cooperation with the Joint Central Team. This engineering effort also includes the associated design integration and work on those aspects which affect the safety of the design and operation of the device. Attention is also being given to finding solutions to ITER design issues that extrapolate to power reactor applications. Supporting this full range of design and technology activities is a program in systems analyses which is used to derive important design insights on ITER-related issues.

There is one additional aspect of the ITER Project I would like to discuss. The ITER Director has noted the importance of identifying the ITER site within the next three years so that site-specific design work can be completed by 1998. Site selection, at both the national and international level, will be a challenging technical and political process. I congratulate the Congress on its support of a timely U.S. effort to identify and select an attractive candidate site in the United States. We should begin this process as soon as possible. There may be the need for some additional funds in FY 1994 for ITER to support site selection studies.

It is of vital importance for the future of the U.S. fusion program to identify and implement a new fusion site, which is qualified not only for ITER but for complementary facilities as well. None of the existing fusion research sites in the U.S. are suitable for such projects. Candidate projects for such a site, in addition to ITER, include a high-energy and high-flux neutron source for materials development and a volume neutron source for fusion nuclear technology development. American industry should play the lead role in establishing and operating this new fusion nuclear site.

In conclusion, Madame Chairman, The ITER Project is proceeding as planned. An international Joint Central Team has been established and substantial progress has been made on the design of the device. The U.S. Home Team is organized and providing strong support to the international effort. We have substantially increased industrial involvement in our ITER program. This will prepare U.S. industry to successfully compete during the construction phase of ITER, provide for enhanced technology transfer from the national laboratories to industry, and generally help U.S. international competitiveness. I also support moving ahead with the process to select a candidate site for ITER in the U.S. We are learning how to make the ITER Project work, literally around the world everyday. I am confident ITER will be a success.

Thank you, Madame Chairman. I would be pleased to answer questions.

Participants in U.S. ITER Project

National Laboratories
- Argonne National Laboratory
- Idaho National Engineering Laboratory
- Lawrence Berkeley Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Princeton Plasma Physics Laboratory
- Sandia National Laboratories, Albuquerque
- Sandia National Laboratories, Livermore

Universities
- Cornell University
- Georgia Institute of Technology
- Massachusetts Institute of Technology
- New York University
- Rensselaer Polytechnic Institute
- University of California at Los Angeles
- University of Illinois
- University of New Mexico
- University of Texas, Austin
- University of Wisconsin

Industries
- CIMCORP Precision Systems, Inc.
- Ebasco Services, Inc.
- General Atomics
- General Dynamics
- Grumman Aerospace Company
- McDonnell Douglas Aerospace
- Pitt Des Moines, Inc.
- Rockwell International
- Westinghouse Electric Corporation

Charles C. Baker
Biographical Sketch

Dr. Baker's academic career began with a B.S. degree in Applied Mathematics and Engineering Physics from the University of Wisconsin in 1966. The following year he obtained his M.S. degree from the University of Wisconsin in Nuclear Engineering. A Ph.D. in Nuclear Engineering, with a minor in Physics, from the University of Wisconsin was granted in 1972. His thesis research was performed on a crossed-field plasma accelerator under the direction of Professor Harold K. Forsen.

Dr. Baker has been actively involved in the fusion community for over 20 years beginning in 1972 as a Senior Physicist at General Atomic (GA) Company in the Fusion Division. While at GA he held various positions including Fusion Technology Department Manager (1974-76), as well as Project Manager of both the TNS Reactor Study (1976-77) and Heating Technology Projects (1977).

From 1977-1989 Dr. Baker was Director of the Fusion Power Program at Argonne National Laboratory where he led the STARFIRE reactor study with Prof. Mohamed Abdou in 1979-1980, and the U.S. Technical Program Analysis Activity (TPA) for the U.S. Department of Energy from 1985-1987.

1988-1989 found Dr. Baker serving as a member of the International Thermonuclear Experimental Reactor (ITER) Conceptual Design Activities team as Head of the Blanket Design Unit. In 1989 he joined the Oak Ridge National Laboratory where he holds his present position as Associated Director for Technology in the Fusion Energy Division.

In 1991, Dr. Baker became Technology Manager for the U.S. International Thermonuclear Experimental Reactor (ITER) Home Team and in November 1992 he assumed the responsibilities of Leader of the U.S. Home Team. He also serves on the international Management Advisory Committee (MAC) for ITER.

Dr. Baker is a past recipient of the DOE Distinguished Associate Award for leadership of TPA (1988); and a past member of the Magnetic Fusion Advisory Committee (MFAC) where he served as Chairman on the Panel on Long-Range Technology.

He is currently an editor of Fusion Engineering and Design, a Fellow of the American Nuclear Society, and actively involved in various committees and reviews in the fusion energy community.

International Thermonuclear Experimental Reactor
U.S. Home Team

FACT SHEET

Purpose

The purpose of the International Thermonuclear Experimental Reactor (ITER) activity is to develop a fusion engineering test reactor to demonstrate the scientific and technological feasibility of fusion power.

International Collaboration

Four international Parties - the European Community, Japan, the Russian Federation (formerly the Soviet Union), and the United States - are collaborating on ITER, with each Party contributing equally to the effort. The work is under the auspices of the International Atomic Energy Agency (IAEA).

Origin

ITER began as an outgrowth of the Geneva Summit of 1985. In 1987, representatives of the four Parties developed a joint-venture plan and established the terms of the endeavor.

Conceptual Design

Conceptual Design Activities (CDA) began in 1988 and were completed in 1990. About 400 person-years of design effort and $100M in validating research and development work were performed. The CDA included:

- An integrated conceptual design of the tokamak and plant,
- A compilation of future R&D needs,
- A plan for the work necessary beyond the CDA,
- A definition of site requirements,
- A preliminary safety and environmental analysis.

The results of the CDA are documented in a series of 18 technical reports.

Current Status

Negotiators for the four Parties developed an international agreement to continue the collaboration into Engineering Design Activities (EDA). The agreement was signed July 21, 1992 in Washington, D.C.

Engineering Design Activities

The tasks for the Engineering Design Activities include:

- Design the device, its auxiliary systems and facilities, and produce engineering drawings of components and their interfaces,
- Establish the site requirements for ITER, and perform the necessary safety, environmental and economic analyses,
- Prepare the program and cost, manpower, and schedule estimates for the operation, maintenance, and decommissioning of ITER,
- Perform the validating R&D including developing and testing of scalable models,
- Prepare proposals for approaches on joint implementation of the future construction, operation, maintenance, and decommissioning of ITER.

ITER Fact Sheet January 1993

The ITER Organization

A multi-national Joint Central Team (JCT) provides the focus for the EDA. The work of this team is conducted at three co-centers:

- San Diego, CA, U.S. - Director - Paul-Henri Rebut, EC, Project Management; Primary Deputy Director - Yasuo Shimomura, Japan, Design Integration; Deputy Director - Valery Chuyanov, Russian Federation, Safety, Nuclear Integration, Engineering.
- Garching, Germany - Deputy Director - Ronald R. Parker, U.S., In-vessel components and related systems.
- Naka, Japan - Deputy Director - Michel Huguet, EC, Ex-vessel components and related systems.

The ITER Council oversees the project and is chaired by E. Velikov, Russian Federation, with a co-chair, M. Yoshikawa, Japan, who also chairs the Management Advisory Committee. The U.S. members of the ITER Council are James Decker, Deputy Director, Office of Energy Research, and N. Anne Davies, Associate Director, Office of Fusion Energy. A Technical Advisory Committee is chaired by Paul Rutherford, U.S. Supporting the Joint Central Team are Home Teams in each of the four Parties which perform specific design tasks and perform the research and development in physics and technology. These tasks are apportioned equally among the four Parties.

The U.S. Effort

U.S. work on ITER is directed and funded by the Office of Fusion Energy (OFE), Office of Energy Research, Department of Energy. The ITER Program Manager at OFE is Thomas R. James.
Leading the U.S. Home Team are:

- U.S. Home Team Leader - Charles C. Baker, Oak Ridge National Laboratory, (ORNL),
- Deputy- Charles A. Flanagan, ORNL,
- Engineering Manager - James N. Doggett, Lawrence Livermore National Laboratory,
- In-vessel Systems Manager - Kenneth L. Wilson, Sandia National Laboratory - California,
- Ex-vessel Systems Manager - D. Bruce Montgomery, Massachusetts Institute of Technology
- Physics Manager - Douglass E. Post, Princeton Plasma Physics Laboratory,

To perform its assigned tasks, the U.S. Home Team draws upon the resources of the DOE laboratories, universities, and U.S. industry.

Schedule

The Engineering Design Activities began in July 1992 and will last six years. Should the Parties agree to continue, construction is estimated to take about seven years. Operations would consist of a first phase, the Basic Performance Phase, devoted primarily to such issues as controlled ignition, extended burn, steady-state operation, and the testing of blankets. The second phase, Enhanced Performance Phase, would emphasize improving overall performance and performing a higher-fluence component and materials testing program. These operations are estimated to last about 20 years.

Estimated Costs

Estimates made during the CDA projected design and technology R&D costs of about $1B (January 1989 US$) over the duration of the EDA. Costs will be shared equally among the four Parties. A preliminary estimate of the capital cost to construct ITER was $4.9B (January 1989 US$).

Further Information

The U.S. Home Team Project Office is located at ORNL.

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Mrs. LLOYD. Thank you, Dr. Baker. We appreciate your testimony as well.

Dr. Davidson, we have a vote right now. So we'll have a short break and we'll hear from you as soon as we return. Thank you.

[Recess.]

Mrs. LLOYD. The Subcommittee will come to order. We will resume our hearings.

And, Dr. Davidson, we look forward to hearing from you.

Dr. DAVIDSON. Madam Chairman, members of the Committee, thank you for this opportunity to testify on behalf of the Princeton Plasma Physics Laboratory and in favor of a revitalized national effort to develop fusion energy. I would like to thank you for your sustained support for the development of magnetic fusion as one of our Nation's long-term energy sources.

I have more extensive written testimony that I would like to submit for the record.

Mrs. LLOYD. And your entire statement will be made a part of the record of the hearing.

Dr. DAVIDSON. Dr. Rebut and Dr. Baker, the other witnesses at this table, have very ably covered the status and plans for ITER. I will limit most of my oral remarks to TFTR and to the Tokamak Physics Experiment. My views on ITER and other elements of the fusion program are included in the testimony submitted for the record.

With regard to ITER, however, I would like to make one point. ITER is a critical technical step in the international quest to develop fusion energy, both with regard to the demonstration of burning plasma behavior and the integration of the nuclear technologies required for a commercial reactor. Dr. Rebut and the ITER team have my full support and the support of the Princeton Plasma Physics Laboratory in this important undertaking.

Let me continue with TFTR status. When the construction of the TFTR began at Princeton in 1976, one goal was to produce fusion plasma temperatures of 100 million degrees Celsius, as required in a fusion reactor. TFTR easily surpassed this goal, producing temperatures of 400 million degrees Celsius and has been a world leader in producing, optimizing, and investigating such high temperature plasmas.

TFTR experiments using tritium as a low-octane fusion fuel have produced world record fusion power for deuterium fuel. This fall TFTR is expected to produce about 5 million watts of fusion power in experiments using tritium mixed with deuterium, a high-octane fusion fuel which will be the fuel mixture used in a commercial fusion reactor.

In 1994, TFTR expects to increase this power level to about 10 million watts, an historic milestone in fusion energy development and about five times the power level produced in the European JET experiment in 1991. Also, far beyond the original goals of TFTR, scientists now project that the initial indications of self-heating of a plasma of by-alpha particles are likely to be detected for the first time in the TFTR experiments. While technical surprises are not anticipated, confirmation of the expected DT results in TFTR is needed in order to proceed with the construction of the ITER device.

I should also point out that the environmental safety and health compliance requirements in preparing to do these historic experiments are proceeding very well, including approval of the environmental assessment, successful public briefings of the surrounding community of our plans, and DOE approval of the final safety analysis report. I'm pleased to report that we have successfully completed the contractor Operational Readiness Review for the tritium systems test and 200 curies of tritium was brought on site last week. The final Operational Readiness Review for the DT experiments is scheduled for June, and we expect to begin those experiments in September.

We have had outstanding technical support from other institutions, including in the tritium area particularly Los Alamos and Savannah River, and we intend to carry out these experiments with exemplary compliance with ES&H requirements and attention to the safety of personnel and the public.

Now on to TPX. The Energy Policy Act of 1992 also calls for the design and construction of a major new national facility for fusion research and technology development consistent with U.S. participation in ITER and industrial participation in the development of the technologies required for fusion. The TPX has been identified by U.S. fusion experts as this major new facility with the goal to improve the performance and effectiveness of the Tokamak reactor concept. TPX would be a unique facility worldwide and will develop improvements leading to new operating modes for ITER, testing of diverter concepts and high heat flux components, and allowing ITER to carry out more effectively its long-pulse technology testing phase.

Very importantly, successful results in TPX will lead to a smaller, more economical fusion reactor that would operate continuously similar to existing power plants. TPX will be the first tokamak with the capability to operate continuously with fully superconducting magnets in the elongated diverge geometry planned for ITER and the fusion demonstration reactor.

TPX construction will also play the very important role of putting U.S. industry in a strong position to compete internationally for major ITER tasks and subsystems, since construction and operation would precede ITER on approximately a five-year time scale.

TPX has been organized as a national activity and is designed to follow TFTR, taking advantage of existing hardware and facilities at the Princeton site. I'm pleased to report that the national TPX team, comprised of scientists and engineers from more than 17 universities, industries, and laboratories, has recently completed the conceptual design of TPX and this design underwent a highly successful conceptual design review by an international committee of experts. And this committee of experts urged proceeding expeditiously with detailed design and construction of TPX.

On behalf of the national team, I request this committee's strong support for design and construction of TPX beginning in Fiscal Year 1994, an essential step to maintain a vigorous U.S. fusion effort, to provide for strong U.S. participation in ITER, and to lead to a more compact economical fusion demonstration reactor.

I would also like to comment on the rate of progress in the U.S. fusion program. Some remarks made earlier suggest to me that the fusion community has not done a very good job in informing you how dramatic the progress, in fact, has been. So the example I would like to compare fusion with is computer memory or the memory on computer chips. If I take 1970 as a benchmark in time relative to now, the computer memory on chips has increased by a factor of 20,000, an incredibly large increase. If I take fusion power produced by the Tokamak approach as a benchmark, again beginning in 1970, using deuterium fuel, fusion devices were producing about one-100th of a watt of fusion power in 1970, and in 1991 in the JET experiments in Western Europe this was increased to about 2 million watts of fusion power, using deuterium/tritium fuel. This is an increase of 200 million relative to 20,000 for the case of computer memory chips. And the TFTR results would increase that by another factor of five to a factor of a billion.

So, in fact, I believe that despite very constrained resources, the progress in magnetic fusion has been rather dramatic and it's been in large consequence due to the great success of the Tokamak approach.

In conclusion, let me thank you for your support of the fusion program over the years. I strongly recommend a renewed national commitment to the development of fusion energy, which is vital to the Nation's long-term economic and energy security.

[The prepared statement of Dr. Davidson follows:]

Statement of Ronald C. Davidson
Director, Princeton Plasma Physics Laboratory
before the
U.S. House of Representatives
Committee on Science, Space & Technology
Subcommittee on Energy
May 5, 1993

Madame Chairman, Members of the Committee -- thank you for the opportunity to testify before this Committee on behalf of the Princeton Plasma Physics Laboratory and in favor of a revitalized national effort to develop fusion energy. I would also like to thank you for your sustained support for the development of magnetic fusion as one of our nation's long-term energy sources.

Role of Fusion Energy

Energy is the lifeblood of our nation's economic and energy security. For this reason, the United States must develop adequate domestic sources of energy. In the short term, energy conservation and increased efficiency are needed, while a secure, environmentally safe energy source is developed for the longer term. Fusion is such an energy source, with a plentiful fuel supply available from the deuterium in ordinary water. Fusion has the potential to satisfy the world energy needs for many centuries without producing acid rain or global warming gases. Fusion will produce very low radioactive waste, and will use materials unsuitable for proliferation of nuclear weapons.

The goal of the Department of Energy's magnetic fusion energy program is to build an attractive fusion demonstration reactor in the 2025 time frame, thereby allowing fusion to be developed as a commercial energy source around 2040. Fusion could be developed on a faster time scale if a stronger national commitment were made.

Providing secure, safe energy for the future of the world's growing and developing population is one of the great challenges facing humankind. I have no doubt that fusion, along with solar and renewable energy sources, will ultimately provide that required energy. What was once thought impossible is now generally accepted, and the debate has turned to the questions: When will we get there and can we afford it? Harnessing the energy process of the stars is a major scientific and technological challenge, but we know the steps required to achieve practical fusion power production, and significant technical progress has been made towards this goal. During the past decade, the rate of progress in fusion could have been greater. The rate of progress has been determined, not by technical impediments, but by the level of effort and national commitment.

The need for new electric power plants is apparent. By the middle of the next century, the world will spend tens of trillions of dollars on electric-generating capacity to replace existing plants and to meet the demands of a growing population. I believe that a significant fraction of that capacity should be provided by fusion plants, rather than the technologies of today that threaten our air, our climate, and even our safety. I also believe that those plants should display labels reading "Made in the USA."

Technical Status

In the 1970s, the United States, Europe, Japan and the Soviet Union made significant investments in the development of magnetic fusion. What has been accomplished with these investments? Let us compare fusion progress with that in computer memory chips. One of the great scientific achievements of the past twenty years has been the fabrication of computer memory chips, which has increased from 120 characters per chip in 1970 to 2,000,000 characters per chip in 1992 -- an increase of twenty thousand. During the same period, magnetic fusion experiments have demonstrated fusion reactions increasing from one-hundredth of a watt in 1970, to 1,700,000 watts achieved on the Joint European Torus (JET) in 1991 -- an increase of one hundred million!

When the construction of the Tokamak Fusion Test Reactor (TFTR) began at Princeton in 1976, one goal was to produce fusion plasma temperatures of one hundred million degrees Celsius as required in a fusion reactor. TFTR easily surpassed this goal, producing temperatures of four hundred million degrees Celsius, and has been the world leader in producing, optimizing and investigating such high-temperature plasmas. The TFTR experiments, using deuterium (an isotope of hydrogen) as a "low octane" fusion fuel to optimize plasma conditions, have produced world-record fusion power for this fuel. This fall, TFTR is expected to produce about five million watts of fusion power in experiments using tritium, a "high octane" fusion fuel, mixed with deuterium, which will be the fuel mixture used in a fusion reactor. This power level is three times the power produced in Europe's largest experiment, JET, which is five times larger in volume than TFTR. In 1994, TFTR expects to increase the power level to about ten million watts, which would satisfy the TFTR design goal established in 1975 for the production of one-to-ten million watt-seconds of fusion energy.

A key remaining scientific issue in magnetic fusion is associated with the self-heating of the plasma by the fusion reaction products called alpha particles, thereby allowing the fusion reaction to be self-sustaining. Far beyond the original goals of TFTR, scientists now project that the initial indications of self-heating of a plasma by alpha particles are likely to be detected for the first time in TFTR. While the TFTR experiments have taken longer than originally projected because of funding limitations, more has been accomplished than was planned, and the funds required to complete the TFTR program will be $250 million less than estimated in the early 1980s. Similarly, the world-wide fusion program has made significant advances in the science and technology goals set forth in the mid-1970s. The time has come to move forward with a new generation of fusion devices to address the technical issues remaining to develop magnetic fusion as a practical energy source.

Near-Term Requirements

The critical tasks required to achieve the goal of a practical fusion demonstration reactor are:

- Determination of deuterium-tritium plasma confinement and alpha-particle heating on the Tokamak Fusion Test Reactor (TFTR), followed by demonstration of a self-heated reactor-grade plasma and associated nuclear technologies on the International Thermonuclear Experimental Reactor (ITER);

- Development of the advanced, steady-state Tokamak Physics Experiment (TPX), a national facility to improve the tokamak concept, leading to a more compact and economical fusion demonstration reactor; and

- Development of low-activation neutron-resistant materials for the reactor structure.

The solutions to these technical tasks are pursued most effectively on parallel paths in a collaborative world fusion program.

The highest priority in the U.S. fusion program is to carry out expeditiously the TFTR program and extract the maximum information on deuterium-tritium plasmas, alpha-particle heating and tritium-handling technology. While technical surprises are not anticipated, confirmation of the expected deuterium-tritium results in TFTR is needed in order to proceed with the construction of the International Thermonuclear Experimental Reactor (ITER).

The U.S. should be a leading partner in ITER, an engineering test reactor to demonstrate the scientific and technological feasibility of magnetic fusion energy, which has been identified as a required step in the development of fusion for more than a decade. The ITER Engineering Design Activities (EDA) is an international collaboration among the United States, Europe, Japan and the Russian Federation. ITER is being conservatively designed to operate reliably on the basis of today's scientific knowledge and is expected to produce one billion watts of fusion power for a duration of about fifteen minutes. In many aspects, ITER will be a reactor prototype that would satisfy the Energy Policy Act of 1992 goal of a technology demonstration that would verify the technical feasibility of fusion power production at the levels required in a commercial power plant. ITER is a very important step in the international quest to develop fusion energy and merits strong support by the United States' Congress, including the identification of a candidate U.S. site suitable for ITER and a fusion demonstration reactor.

The Energy Policy Act of 1992 also calls for the design and construction of a major new national facility for fusion research and technology development consistent with U.S. participation in ITER and industrial participation in the development of the technologies required for fusion. The Tokamak Physics Experiment (TPX) has been identified by U.S. fusion experts as this major new facility with the goal to improve the performance and effectiveness of the tokamak reactor concept. TPX will be a unique facility worldwide and will develop improvements leading to new operating modes for ITER, testing of divertor concepts and high-heat-flux components, and allowing ITER to carry out more effectively its technology testing phase. Very importantly, successful results on TPX will lead to a smaller, more economical fusion reactor that would operate continuously, similar to existing power plants. TPX will be the first tokamak with the capability to operate continuously with fully superconducting magnets in the elongated divertor geometry planned for ITER and the fusion demonstration reactor. TPX construction will also play the very important role of placing U.S. industry in a strong position to compete internationally for major ITER tasks and subsystems. TPX has been organized as a national activity and is designed to follow TFTR, taking advantage of existing hardware and facilities at the Princeton site.

I am pleased to report that the national TPX team, comprised of scientists and engineers from more than seventeen universities, laboratories and industries, has recently completed the conceptual design of TPX, and this design underwent a highly successful Conceptual Design Review (CDR) by an international committee of experts who urge proceeding expeditiously with detailed design and construction of TPX. On behalf of the national TPX team, I request this Committee's strong support for design and construction of TPX starting in FY94, an essential step to maintain a vigorous U.S. fusion effort, to provide for strong U.S. participation in ITER, and to lead to a more compact, economical fusion demonstration reactor.

The design and construction of TPX and ITER benefit significantly from the results of existing tokamak experiments, such as the DIII-D device at General Atomics, PBX-M at the Princeton Plasma Physics Laboratory, and Alcator C-Mod at the Massachusetts Institute of Technology. These devices are testing concepts that improve tokamak performance at short pulse lengths or develop advanced divertor configurations that withstand high heat fluxes. I urge strong support for operation of these facilities and for upgrades of the DIII-D tokamak at General Atomics.

A strong national effort in the science and technology of fusion is needed to attract and train a new generation of skilled fusion scientists and engineers to carry out fusion energy development during the next decades. The R&D record of our nation's fusion scientists and engineers has been outstanding at universities such as the Massachusetts Institute of Technology (MIT), the University of California at Los Angeles (UCLA), the University of Texas at Austin, the University of Wisconsin and Columbia University, at national laboratories such as the Princeton Plasma Physics Laboratory (PPPL), Oak Ridge National Laboratory (ORNL), the Los Alamos National Laboratory (LANL) and the Lawrence Livermore National Laboratory (LLNL), and at industries such as General Atomics, Ebasco Services Incorporated, General Dynamics, Grumman, McDonnell Douglas, Westinghouse, and Varian Associates. A vigorous national infrastructure in fusion is essential for effective United States' participation in ITER and in the design and construction of TPX.

Finally, as continued progress is made in the resolution of fusion physics issues, more attention must be given to the development of the materials for fusion reactor structures to ensure that the full potential of fusion is realized. I urge support for research and development of low activation materials and for the construction of an international Fusion Materials Test Facility which could be operational around the year 2000.

In conclusion, let me thank you for your support of the fusion program over the years. I strongly recommend a renewed national commitment to the development of fusion energy, which is vital to the nation's long-term economic and energy security.

Mrs. LLOYD. Thank you very much, Dr. Davidson.

It's my understanding that TPX is an opportunity for us to gain experience in design and the construction of a Tokamak; is that correct?

Dr. DAVIDSON. That's correct.

Mrs. LLOYD. That is, the purpose of the project is not to study fuels or other elements of the fusion program?

Dr. DAVIDSON. The TPX device would use deuterium fuel and the main scientific missions of the device would be to demonstrate continuous operation. It would make use of noninductive current-drive techniques. It's a superconducting magnet device. It would allow the device to operate in true steady state or continuously, like we would hope a fusion power reactor would do.

Another important element of the scientific mission is to explore concept improvement, explore ways in which Tokamak can operate at higher values of power density, thereby leading to a more compact and economically attractive fusion power reactor.

Mrs. LLOYD. Do you feel this will be completed in time to have an impact on ITER?

Dr. DAVIDSON. I believe it will have an impact on ITER in several ways. The project schedule for TPX would begin design and construction in 1994 and 1995, with initial operation as early as 1999. There would be operating experience on the device in testing advanced divertor concepts, advanced high heat flux components, which I think would have a very important impact on the ITER design of those components and operation.

Also, the TPX device would be the first device to operate at moderately high power densities for pulse lengths of a thousand seconds or more, and there would be experience gained on TPX in handling plasmas of such high power densities for very long pulses, which is of great importance for ITER operation, which would also operate in the several hundred second pulse length range.

Mrs. LLOYD. Thank you.

Dr. Rebut——

Dr. DAVIDSON. If I could also add, I believe critical for TPX will be, since it would be a construction project with many high-technology components, superconducting magnets, divertors, vacuum vessel, remote handling, this would really enable U.S. industry on a smaller scale, but with an important high-tech project to be prepared, if you like, to be quite competitive on the subsystems for ITER.

Mrs. LLOYD. Thank you very much.

Dr. Baker, is the United States participating in a siting effort? What is the criteria and other siting conditions?

Dr. CHARLES BAKER. At the end of the conceptual design phase, which was completed in 1990, preliminary information was developed on the site requirements for ITER in terms of physical area, electrical power requirements, cooling, and the like. The design now is being revised and we'll change those requirements somewhat, and I believe Dr. Rebut and the Joint Central Team will update those requirements over the coming year. But we have a general idea, but they will become more specific as the design becomes more specific.

Mrs. LLOYD. Dr. Rebut mentioned the fact that—or it might be an earlier witness mentioned the fact that—perhaps the design—the site selection should be done perhaps a little earlier in view of the fact that it will have some impact on the design. Would you like to comment on that?

Dr. CHARLES BAKER. Yes. As I said in my remarks, we have a six-year design process. At the end of that time, we are to be able to make a decision on proceeding with construction. Some of that design work will depend on the particular features of the site, seismic requirements, for example.

So in looking at that and backing up, it tells you you'd like to know that site about two years before the end of this period, which is about three years from now. If you look at the process or at least anticipate the process to go through an international selection and then say we need some internal or U.S. selection process, I think you can't help but come to the conclusion it's time to start.

Mrs. LLOYD. I agree with you.

What is your primary area of your home team effort? I know that you're very much involved with industry and several universities and laboratories, but what is your primary mission of our home team?

Dr. CHARLES BAKER. Well, our primary mission is to support the international effort and to do those tasks that are assigned to us by Dr. Rebut and the Joint Central Team.

Mrs. LLOYD. I guess what I'm asking, What are your assigned tasks?

Dr. CHARLES BAKER. We are in the process now of working out the task agreements. Some specific areas, such as magnets, are well along and tasks have been assigned to the United States, such as buying superconducting wire and doing design of magnets, and our industrial team is quite active in that.

In other areas, we are now moving from basically a domestic program to one that's tied in in terms of formal agreements with the Joint Central Team, and that process will go on for this coming year.

Mrs. LLOYD. Who else is working on the magnets besides the United States?

Dr. CHARLES BAKER. All the other parties are working on the magnets. It's truly an international effort.

Mrs. LLOYD. How many types of magnets are we working on?

Dr. CHARLES BAKER. There are two types of magnets that ITER requires, in fusion parlance, so-called toroidal magnets and poloidal magnets. The scheme has been developed to divide that responsibility in an equitable fashion among all four countries; also, to divide the test facilities and to share the fabrication of the wire, the superconducting wire, which will help qualify industries both in the United States as well as in the three other countries.

Mrs. LLOYD. Thank you very much.

Dr. Rebut, what will ITER do to accomplish our goal of fusion power plant demonstration that we haven't done for JET or JD60 or TFTR, for the record?

Dr. REBUT. Yes. I suppose in JET and in TFTR, what we will have done is basically demonstrations that we can control the plasma in terms of a physics object. In JET we have realized, I must say, the right temperature. We have realized the right density and the right time of confinement. So each requirement for a reactor, these are things that we have not done because the mission is too small to do these at the same time, but to have done this on one machine means that we are very confident of the extrapolations of JET results to a reactor, a full reactor. So ITER will be such a reactor, and in this sense it will reach what is called ignitions, which means that heat developed by the fusion reaction in ITER will be sufficient to maintain the temperature of the plasma. We don't need an additional heating, as all the other missions have been done. So ITER will be the first time or the first mission which will burn, if I may say freely, nuclear fuel.

Mrs. LLOYD. Mr. Fawell?

Mr. FAWELL. Let me make a reference to one of Dr. Hirsch's observations, if I may. I guess the question can be directed at any one of the three of you.

Dr. Hirsch did observe that there are what he called enormous materials problems related to DT fusion in general, stating that there were no qualified materials to date for DT fusion reactors. In the absence of development of a low activity material under a costly and time-consuming undertaking, you will have to effectively rebuild your fusion reactor every five to ten years and dispose of many times the amount of radioactivity that would come, for instance, from a fission reactor of the same power level.

Who would like to try that one? Dr. Rebut?

Dr. REBUT. Yes, thank you.

I must say, first, you have to distinguish in the materials for the first wall which receives the neutrons. And, obviously, these materials will have to be disposed and changed if they are destroyed by the neutrons. We are looking now to two things. Even for ITER we are looking to use low activation material for the first wall, if we can. Of course, we have in mind to push development basically in sites of different parties for this material now. So development of material does not progress; nobody is asking for this material. So I hope that first we will be able to have this low activation material as a first wall for ITER.

Secondly, the concept of the system is to have a very thin first wall—I'm speaking of millimeters, nothing else—in order to limit the amount of this material to be changed.

And, thirdly, this material I hope will be recycled—you can recycle this material for a new wall, so they are not wasted in this sense.

Mr. FAWELL. I think I understand, but, Dr. Baker, would you also like to——

Dr. CHARLES BAKER. I'd like to make a general comment and perhaps somewhat of a more technical one. I heard Dr. Hirsch's remarks directly. They are not new. These concerns have been with us, with all of us, for a long time. If Dr. Hirsch offered an alternative to the Tokamak reactor and the deuterium/tritium fuel cycle, then I'd be much more sympathetic to his line of argument, but he doesn't really say what he would do instead, at least that I have not heard.

It's all too easy to criticize what we know the most about in the hope that something else will look better. That's not to say we shouldn't continue to look for the better, different things, but I think if in the process of doing that you tend to say what we now are doing and what we know the most about looks bad and we shouldn't do it, I don't believe that's very responsible.

A specific comment on the idea of the materials question. It is true in the deuterium/tritium approach to fusion you have some significant materials problems, most notably the effects of the high energy neutrons. It is not true that the other fuel cycles have easy materials problems. They have different materials problems.

It turns out that in these other fusion fuel cycles most of the energy comes out of the plasma in terms of a surface heat flux. It stops right at the first surface and creates a very difficult engineering problem. The neutrons, which are part of the problem in deuterium/tritium fusion, have the great advantage that they penetrate a bulk component and spread the heat out. As an engineer, I'd rather cool that bulk heat than take it all out of the surface, all other things being the same.

So the sense that these alternatives are all so good and great and what we know the most about is bad has got it out of balance. It's just not quite all good and all evil. It's a little bit of both.

Mr. FAWELL. You don't foresee a rebuilding of the reactor every five or ten years, as Dr. Hirsch has referred to?

Dr. CHARLES BAKER. That's taking face value also wrong. The part that would need to be replaced is the so-called first wall and blanket, which accounts for only 10 percent of the reactor, and that's the only part being replaced. The vast body of the reactor, the shielding, the magnets, the vacuum vessel will last the entire life of the reactor in a deuterium/tritium system.

Many years ago we thought that in a deuterium/tritium system we'd have to change it every year because we didn't know much about materials. Now we know more and can have confidence it will last at least five or ten years. We believe we can change out those materials in the same time that a present-day power plant shuts down for routine maintenance. If you can do that—I'm not saying we know how for sure, but if you can do that, then this change-out time is not a problem.

Mr. FAWELL. Dr. Davidson, what are the ramifications of the DT experiments in TFTR for decontamination and decommissioning of the TFTR once the DT experiments are finished, now that tritium is coming into the picture?

Dr. DAVIDSON. Well, beginning in September of this year and continuing through September of 1994, we will carry out about 600 to 800 major experimental shots using the deuterium/tritium fuel mixture in TFTR. And at that level of performance, the device, through the neutrons interacting with the surrounding structure of the device, will become activated.

In about a year's time following completion of those experiments, it will be possible to essentially disassemble, begin to disassemble, the device and then remove it, remove it from the site, in order to install the follow-on facility.

So the decommissioning for TFTR will take place over about a two-year, a two-to-three-year period.

Mr. FAWELL. Are there major problems involved because of that——

Dr. DAVIDSON. There are not major problems involved.

Mr. FAWELL [continuing]. High radioactivity involvement?

Dr. DAVIDSON. There are not major problems involved. In fact, the most outer extremities of the facility, the neutral beam heaters, the diagnostics and the periphery of the device, even right after operation, you could have hands-on modification of the device. In the reactor core itself, it becomes much more activated and hotter, and it's those regions of the device that would undergo about a year cool-down period before you disassemble it.

Mr. FAWELL. All right, let me ask you this question: What will we learn from DT experiments in the TFTR that hasn't already been learned from those types of experiments in JET?

Dr. DAVIDSON. Well, one thing that we will be doing in TFTR is a very extensive experimental campaign. The Joint European Torus, as I recall, did two DT shots with relatively low tritium concentration. We will be doing a rather extensive number of DT shots, shots with tritium, using 50/50 concentration of deuterium and tritium. And this will allow us to explore in some detail the effects with deuterium/tritium plasma of equilibrium, stability, transport processes that we know very well can deteriorate in plasmas, but have not been documented thoroughly in DT fusion plasmas. We will be able to understand those processes much better.

We will also have the opportunity at the power levels I mentioned to see the initial evidence, we believe, of the alpha particles producing some self-heating of the plasma. This, of course, is a major mission of the ITER device, which will be ignited. So we believe that the TFTR experiments will provide very important support for the ITER design assumptions and construction of that device.

Mr. FAWELL. Just one last question: you've heard my question before in regard to utility industry interest, and we all heard the answers, that basically this is so long term, et cetera, et cetera, that understandably utility interests are interested in near term, and so forth. But still that nagging feeling that there have to be people in industry, in the utility industry, who are pure theorists who are doing this because their grandchildren are going to benefit from this, knowing it's not going to help anybody in the near term.

Is there really a lack of interest in those people who should in theory interest—as I think all of you gentleman have? You're not in this just for your health. It's something that you deeply believe in.

There's a lot of industry people who believe in it. They are all financially involved, too, a great degree. Why aren't——

Mr. DAVIDSON. I would say that the fusion community has not done a good job in keeping what you call the utility industry abreast of progress. In addition, from the utility industry point of view, fusion is very long term and they're not yet pounding on our doors wanting to know when the technology will be ready to deploy.

I would also reiterate a point that Harold Forsen made earlier. When you speak of utility industries, I think for the most part you're thinking of the operators of the utilities. It's really a large number of other industries who supply the components for utility devices, whether they're fission or coal-fired plants, or whatever. And with regard to those industries, in fusion we have very strong industrial involvement, I believe, among the Bechtels and other very high-technology industries.

Mr. FAWELL. Thank you very much.

Mrs. LLOYD. Thank you very much.

Before the Chair recognizes Mr. Scott, I would like to thank the witnesses for the testimony they have provided us today. Mr. Swett will preside and receive the testimony from our final panel, but I do want to thank all of the participants today, as well as the staff, for a good hearing.

Mr. Scott?

Mr. SCOTT. Thank you. Thank you, Madam Chairman. I just have a couple of questions.

Dr. Baker, in the site selection you mentioned the area of power and cooling. In selecting the site, will any infrastructure requirements be there, any available job skills of the workforce in the area, and proximity to colleges and other research areas—will they be issues involved?

Dr. CHARLES BAKER. Yes, of course, all those will be very important issues. There will need to be a substantial infrastructure, hopefully, an existing one to minimize the cost and provide the support services, engineering capability, and the like.

The nature of the surrounding area will be important because, keep in mind, if we're talking about ITER, this is an international project. We must provide the schooling, the ability to employ spouses and the like, that will attract families of the best scientists and engineers from around the world. So, yes, all these things will be very important besides just the technical features.

Mr. SCOTT. Is this going to be built in the United States?

Dr. CHARLES BAKER. We don't know that. We would hope so. What we hope to do is have the Department of Energy undertake a process to lay out how we would go about site selection in the United States. It's my understanding that they're working on a plan that was a requirement of the appropriations last year, and that plan is to be submitted to the Congress, I believe, by the end of this Fiscal Year. Someone here from the Department of Energy may want to add to that. So, hopefully, that will go forward. That will lay out some kind of national process, some kind of competition, I would imagine, and then after that we will then pick probably one site in the United States and then the other countries will offer their sites, and there will be some international competition.

Mr. SCOTT. Mr. Rebut or Dr.—pronouncing your name Rebut, is that——

Dr. REBUT. Rebut.

Mr. SCOTT. You mentioned in your statement the full participation of industry. Obviously, the Federal Government is investing heavily. What participation would industry have and how could we sell industry on participation in such a project when apparently the commercial applications won't be available for many years?

Dr. REBUT. Yes. There are, I believe, two aspects to this question. There is a general aspect, which is participating from the industry to advance technology development, and already, I must say, I don't know very much in this country, but at least in JET with the European industry they have been able to get some—the knowledge of some advanced technologies which have been used in other fields. And I must say in terms of producing high power or RF equipment, for example——

Mr. SCOTT. In terms of producing what?

Dr. REBUT. RF equipment, radio frequency equipment, high-powered loads which are in the same range as the television ones, cable, transport for liquid tritium, liquid nitrogen, and so on. I would not—there is a long list of things which have been beneficial within the fuels industry. And this is one aspect.

The second aspect for the industry is to be acquainted with technology which can be used in a fusion reactor on a longer time scale. And this I believe it is important because it will be industry which will build the reactor correctly. Even for a machine like JET and ITER, all the components have been built at least for JET by the industry, and for ITER they will be built by the industry.

ITER is also an international project, and in this respect I suppose that the industry and the different parties will have to learn to work together, and this is something which is new, but I believe which is also important.

Mr. SCOTT. When you say full participation of industry, are you suggesting that they should, in addition to working with the program and generally support it, have a financial contribution?

Dr. REBUT. This is a very difficult question for me because it depends on the general whole attitude of the parties which, I must say, are quite different between this country, Europe, Russia, and so on, and Japan. So I cannot really answer on this question.

Dr. CHARLES BAKER. If I may, I'd like to add to that briefly. I took the sense of your question: Why would industry want to get involved in fusion now if it's so far in the future? And I think there are at least three reasons.

One, if ITER goes into construction, it's a multibillion dollar construction project. It would offer major opportunities for architect-engineers, the Bechtels, the Ebascos, and those major companies.

Secondly, we will spend some $450 million in R&D and design work in this six-year period, and industry would like to have a good share of that R&D work, learn how to make these components, better materials, and the like.

And, third, it's not true that the commercial application of fusion is necessarily that far in the future. There are substantial spinoffs that develop: new materials, superconducting magnets, computers, electronics. Fusion has contributed substantially to that already, and these companies like to get involved now because it helps them in their other businesses.

Mr. SCOTT. The $450 million R&D and design work, will that be essentially bid on a national or international basis?

Dr. CHARLES BAKER. That represents the U.S. portion of the ITER program. We have at this point selected competitively a number of industrial teams. They've already been selected and they will get contracts in various areas. It will depend, to some degree, on the international sharing of the work, but that competitive process has taken place and the contracts are already started.

Mr. SCOTT. Are these American firms or international firms?

Dr. CHARLES BAKER. No, I'm speaking of the American firms, and the same thing is going on in the home teams of the other countries. And, for this reason, as Dr. Rebut said, I think it will help our American industry in terms of the international competitiveness because they will work out joint arrangements with companies in other countries.

Mr. SCOTT. The firms have already been selected?

Dr. CHARLES BAKER. Several have been. We have selected nine so far. We're about to add three or four more, and we may be adding more after that.

Mr. SCOTT. Could you provide us with a list of the firms and what their ability to——

Dr. CHARLES BAKER. The list is in my testimony.

Mr. SCOTT. And what they're doing and what they expect to find out in their research, that's in your testimony?

Dr. CHARLES BAKER. Yes, I've given the areas. If you would like more information, please let me know and I'll provide further written information.

Mr. SCOTT. Thank you, Mr. Chairman.

Mr. SWETT [presiding]. Thank you, Mr. Scott.

I understand that we have one more member who would like to ask some questions. So I'll turn the microphone over to Mr. Klein from New Jersey.

Mr. KLEIN. Thank you, Mr. Chairman.

First of all, I would like to welcome Dr. Davidson from New Jersey to the hearing. He's already been welcomed officially by the Chair, but I take special pride in the fact that New Jersey is the site of one of the most vital parts of this very, very important program which has so many ramifications, scientific to be sure, but economic, political—political in the sense of world geopolitics, and the potential for it is enormous. And it's exactly the kind of project that we on this committee should be supporting fully because of this long-range potential for the betterment of the United States in so many, many ways.

Dr. Davidson, I apologize because with the rather hectic schedule I may have, I may ask a question that may be repetitive to something that someone else asked, and if so, don't hesitate to advise me of that. But, as I understand it, the deuterium/tritium—and I don't know whether I pronounce that word correctly—tritium experiments on Princeton's Tokamak will begin this fall, and it will be using a DT fuel mixture.

What do we expect to learn from these experiments?

Dr. DAVIDSON. I covered that partially in my testimony, but let me reiterate. At those power levels there is sufficient alpha particle concentration in this plasma that we may see some of the initial effects of self-heating by the alpha particles. This is extremely important—that we understand this scientifically. We anticipate that these alpha particles will not be detrimental to confinement properties of the plasma, but we will certainly be able through those experiments to validate many of the assumptions made in the ITER design.

I think also it will be really quite a landmark for the U.S. fusion program. The TFTR experiments were commissioned well over a decade ago with this objective in mind of producing significant amounts of fusion power. And on two occasions, the DT plans for TFTR have been deferred. So I believe that this is an important opportunity for the national fusion effort, first of all, to carry on its commitment to the United States Congress and also to make significant scientific progress in the international quest to develop fusion.

Mr. KLEIN. Dr. Baker, maybe this question should more properly go to you, and it's a followup of a statement you made in response to one of Mr. Scott's questions. The side effects or the spinoffs, spinoff technologies, is there any estimate as to what the potential commercial value of those spinoffs are, and can we fairly say that this experiment even pays for itself in the short run?

Dr. CHARLES BAKER. I don't know how to put a dollar value on that, which in the spirit of what your question asked, I think, would be that precise. Probably to say that those spinoffs have generated business at the level you suggest probably is not true—I really don't know.

It is difficult to add up how it might have an impact in other businesses. We do know in a more qualitative way all the things that have benefited from both magnetic and inertial fusion research, and I think it's been substantial. But I think it would be a bit ambitious to say that it's paying for it in that sense.

Mr. KLEIN. One other follow-up question: you said that American firms will participate in the contracts for the construction. Can we also assume that the workers involved in this project will essentially be American workers?

Dr. CHARLES BAKER. As I said, the phase that we are now involved in ITER is an agreement by the U.S. Government and the other governments to carry out an engineering design. The governments have not formally agreed to a construction phase. That decision and agreement would come a few years from now. If that decision is made, then one would have to decide where to build ITER. Regardless of where it's built, if it's a multi-government agreement, all the governments—and, therefore, all the industries—will share one way or the other in that project.

It's likely that the place where it's built will get most of, you might say, the construction jobs for buildings and things of that sort, as you would expect, but the actual fabrication of the components—and, therefore, the experience you gain to build fusion reactors—would be shared among all the international teams.

Mr. KLEIN. Thank you very much.

Mr. SWETT. Thank you very much, Congressman Klein.

We conclude the second panel with that array of questions, and we thank the panel for their testimony and for fielding those questions. You are excused.

And we will bring forth the third panel at this time. Good afternoon. This is the conclusion of a long day, I'm sure, for all of you, and I appreciate your patience in waiting for the previous two panels to conclude their remarks. You have the unenviable position of being the last to speak, but I think having heard everybody else's testimony, you have the advantage of being able to use what was said before you, hopefully, to your advantage and that will improve your testimony, if I know any of you and your talents at all.

I'm happy to welcome Dr. Berkner, the Associate Laboratory Director of Operations at Lawrence Berkeley Laboratory, Berkeley, California; and Dr. Bogdan C. Maglich, the chief scientist, Advanced Physics Corporation, Irvine, California; Dr. Edmund

Storms, the staff member from Los Alamos National Laboratory, Los Alamos, New Mexico; and Dr. Randall L. Mills, for the Hydro-Catalysis—am I pronouncing that correctly? Hydro——

Mr. MILLS. Catalysis.

Mr. SWETT [continuing]. Catalysis, OK; I thought there was an extra syllable in there—Power Corporation in Lancaster, Pennsylvania.

I would like to proceed in that order with your testimonies, and we will reserve questions from the members at the conclusion of that testimony.

Dr. Berkner, please begin.

STATEMENT OF DR. KLAUS H. BERKNER, ASSOCIATE LABORATORY DIRECTOR, OPERATIONS, LAWRENCE BERKELEY LABORATORY, BERKELEY, CA; ACCOMPANIED BY DR. BOGDAN C. MAGLICH, CHIEF SCIENTIST, ADVANCED PHYSICS CORP., IRVINE, CA; DR. EDMUND STORMS, STAFF MEMBER, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM; AND DR. RANDELL L. MILLS, PRESIDENT, HYDROCATALYSIS POWER CORP., LANCASTER, PA

Dr. BERKNER. Mr. Swett and Members of the Subcommittee, thank you for having me here. I have prepared a written statement which I'd like to submit at this time.

Mr. SWETT. Without objection, so ordered.

Dr. BERKNER. Anne Davies, when she described the program in the Office of Fusion Energy, mentioned that the preponderance of the program is in magnetic confinement, but that there is a small component in inertial fusion. I want to talk to you about the heavy ion fusion development program, the research program that's carried out primarily at the Lawrence Berkeley Laboratory, and why it differs from the defense program's applications.

Fundamental physics define what fusion reactions are, and you've heard a lot today about the D-helium-3 reaction. That was one of the reactions recognized early on, but the one that's "the easiest," because you get the most gain and you are able to initiate it more readily, is the deuterium/tritium reaction. Even that, as you've noticed, is extremely difficult.

The two programs that have been looking at deuterium/tritium are magnetic confinement and also inertial-confinement fusion, where you take small pellets, you deposit a lot of energy on the surface to implode those pellets, creating the fusion reaction. That program, because it has military implications in that it looks somewhat—in that the processes are somewhat like a miniature bomb—has been carried by the Defense Programs part of the Department of Energy. It is their job to demonstrate the target physics and the scientific feasibility of inertial fusion. They have made tremendous progress in the last two years, and they are starting on a laboratory ignition facility whose job will be to do the final laboratory demonstration.

However, for energy applications, you need efficiency and you need a repetition rate in the driver, in the part of the experiment that makes the pellet implode. Those are requirements that are not required for Defense Programs because they're quite satisfied with having one shot a day. If you compare that with underground tests where there are a few a year, even one shot a day is quite rapid.

In Defense Programs you're not concerned with efficiency because, again, you're interested in the energetics of the implosion, not the energetics of the total system, and the idea to gain power. So you would have to think of a totally different driver, a driver that is not particularly of interest to the defense programs; namely, one with high efficiency and high repetition rates.

Heavy ions have been identified as the leading candidate for energy applications by numerous panels. There is a large experience base in accelerators. The high energy physics community worldwide has developed accelerators that operate day-in, day-out, many of them for 30 years or more. At Berkeley, we recently closed down the Bevatron, which had run for 39 years.

Early experience on transporting beams of ions show that they have great promise for this application, and theory also predicts that they will be the application that you can use as a driver for an inertial fusion target.

The things that are new are high instantaneous beam power. We're talking about a hundred trillion watts on target, and at the same time maintaining focusability so that this beam can be focused down to a spot the size of the pellet, which is a few millimeters.

One may well ask the question: why not use heavy ions for the target physics experiments? The answer is quite simple. Heavy ions are not far along on the development path to be able at this time to deliver considerable amounts of energy, and so if your interest is in target physics, then you use those drivers that have the most energy available right now, and those are lasers and light ions.

Because of this, the heavy ion program has been in the Office of Energy Research within the Department of Energy. For a long time the program was in the Office of Basic Energy Sciences and in Fiscal Year 1992 it was transferred, at the advice of the Fusion Policy Advisory Committee, to the Office of Fusion Energy. So what we call the inertial fusion program in the Office of Fusion Energy is the development of heavy ion drivers.

The next step in this program has been identified as a facility called ILSE, the Induction Linac Systems Experiments, that would demonstrate that full-scale beams can survive the various manipulations that you would require in a driver. It would not be a driver facility. It would demonstrate the characteristics that you need. We have just completed a conceptual design for that, and the total estimated cost for the project is $44 million over three and a half years.

The ILSE experiment has been talked about for about five years, and it has the endorsement of many major national committees. The JASONS have reviewed it and recommended our proceeding with it. The Fusion Policy Advisory Committee, the blue ribbon panel that was put together and reported out in 1990, recommended heavy ions as the first choice for a driver development path for commercial energy from inertial fusion.

The National Academy of Sciences, which was reviewing the inertial confinement fusion program at the same time, although it primarily focused on the target development, did again endorse the ILSE program as one for the energy development path. And, most recently, the Fusion Energy Advisory Committee formed Panel 7 to look at that; and, at their April meeting, the Fusion Energy Advisory Committee strongly endorsed proceeding with the ILSE series of experiments as a proof of principle. They also strongly urged the support be found somewhere in this program to support those experiments.

The reality of the situation is that heavy ion fusion research has not done well in funding. It has done extremely well in reviews. I'm not sure of too many programs that have had so many major reviews that are consistently positive.

When we were in Basic Energy Sciences, our budget was held steady, but their advisory committee said that this was an energy program; it was not quite appropriate for Basic Energy Sciences. We were transferred to the Office of Fusion Energy, and we started with a budget of $9 million in Fiscal Year 1992. That dwindled to 8 in Fiscal Year 1993, and, unfortunately, we are scheduled—we are slated for a budget of $4 million in Fiscal Year 1994.

To proceed with a program of proof of principle, what the ILSE program encompasses, we're talking about a $20-million-a-year program. As you can see, with $4 million, the best we could hope during Fiscal Year 1994 is to keep the program, the major people in the program alive for a start in Fiscal Year 1995, and we hope that that will be forthcoming.

Thank you.

[The prepared statement of Dr. Berkner follows:]

HEAVY ION INERTIAL FUSION ENERGY PRODUCTION

Testimony

to the

Subcommittee on Energy

Committee on Science, Space, and Technology

by

Dr. Klaus H. Berkner

Associate Laboratory Director

Operations

Lawrence Berkeley Laboratory

May 5, 1993

Chairman Lloyd and Members of the Subcommittee:

I am Dr. Klaus Berkner, Associate Laboratory Director at Lawrence Berkeley Laboratory. I appreciate this opportunity to discuss the inertial fusion energy program. As you know, there are two principal approaches to fusion energy: magnetic confinement fusion and inertial confinement fusion. In inertial fusion, small targets containing thermonuclear fuel are ignited by intense laser or particle beams. The targets explode, creating bursts of energy that can be contained in a target chamber or reactor. The heat from these microexplosions can be used to generate electricity. The targets typically have a radius of a few millimeters and the target chamber has a radius of a few meters. The beams from the laser or particle accelerator (the driver) are focused by lenses outside the chamber onto the target located at the center of the chamber.

While inertial fusion and magnetic fusion share many important benefits such as the promise of safe, environmentally benign energy and a nearly limitless supply of fuel, there are also important differences in physics, engineering, and materials science. The diversity created by developing two approaches greatly increases the probability that fusion will become an economical and environmentally attractive energy source. Ultimately, scientific considerations or funding constraints may force a selection between the two approaches. It is certainly too early to make a sound scientific selection. The Fusion Policy Advisory Committee, which was chartered to conduct a major review of the fusion program in 1990, recommended research on both approaches until feasibility of practical fusion energy is demonstrated.

As you know, the magnetic fusion program, which was described earlier in this session, is supported by the Department of Energy's Office of Energy Research. The creation of small thermonuclear microexplosions is relevant to nuclear defense, and the Department of Energy, through its Defense Programs, has supported the construction of lasers and light-ion accelerators to address the scientific feasibility of inertial fusion. Experiments using the Nova laser at Lawrence Livermore National Laboratory, the PBFA-II accelerator at Sandia National Laboratories, the Omega laser at the University of Rochester, and nuclear explosives at the Nevada Test Site have already put to rest fundamental questions about the basic feasibility of inertial confinement fusion. There are important research programs at Los Alamos National Laboratory, the Naval Research Laboratory, General Atomics, universities, and elsewhere.

While much of the science emerging from the defense programs is applicable to inertial fusion energy, some of the technology is not. For defense applications, the pulse repetition rate of the driver is relatively unimportant, and a few shots per day are adequate. For power production, however, a high pulse repetition rate (several per second) is required. Moreover, the driver must be reliable and efficient and must have a long life (about thirty years). The drivers constructed by Defense Programs — lasers and light ion accelerators — are excellent for near-term research, but they have been designed for low repetition rate, typically a few shots per day. Consequently, development of different drivers is needed for power production. During the last decade nearly all high-level DOE and Congressionally mandated committees have identified heavy ion accelerators as the most promising drivers for power production. Because the goal is commercial energy production rather than defense, the Inertial Fusion Energy (IFE) program is the responsibility of the Office of Fusion Energy.

Accelerators for fusion, designed to accelerate ions such as cesium or xenon, are similar in many respects to the large, high energy accelerators that are used worldwide for basic physics research. These accelerators represent a multi-billion dollar investment which provides the experience base for driver development. Many of the requirements of inertial fusion have been demonstrated in existing accelerators. In particular, these accelerators usually have excellent reliability, long life, and high pulse repetition rates. The new requirement for fusion is the production of very high instantaneous beam power, greater than 100 trillion watts, while maintaining focusability adequate to hit small targets. There are two main methods of acceleration: induction acceleration and radio frequency (r.f.) acceleration. The r.f. approach is being studied in Europe and elsewhere. We work closely with our foreign colleagues, but we have chosen to develop the induction approach in the U.S. Our studies indicate that the induction approach is less complicated and less expensive than the r.f. approach. The induction approach is inherently suited to high power, and it is almost exclusively a U.S. technology.

Heavy ion fusion offers a unique opportunity. It combines the science and technology of defense with the science and technology of high energy and nuclear physics to create a promising commercial energy option. Because of the large past investments by Defense Programs and High Energy and Nuclear Physics, modest incremental funding can create an advanced fusion option.

During the last decade we have performed a number of relevant experiments on small accelerators at the Lawrence Berkeley Laboratory. These experiments have confirmed our theoretical expectations. However, the beams used in these experiments were smaller and had lower electrical current than those needed for a power plant driver. To continue progress, heavy ion fusion researchers have proposed a new accelerator facility known as ILSE (Induction Linac Systems Experiments). The Department of Energy officially approved a mission need statement for such a facility in March 1992. In response to this statement of need, Lawrence Berkeley Laboratory, in collaboration with Lawrence Livermore National Laboratory, has prepared a conceptual design report that was submitted to the Department of Energy in April 1992. The report has been updated and was recently resubmitted.

The ILSE accelerator will have full-scale beams and will test all beam manipulations required in a power plant driver; however, it will accelerate the ions to lower velocity than a driver. Assuming ILSE is successful, it will be necessary to build a larger accelerator to achieve fusion energy. Nevertheless, ILSE represents a necessary and significant step.

We have sought industrial and university participation in the ILSE project, and we frequently collaborate with other U.S. laboratories. Titan/Pulsed Sciences Incorporated of San Leandro, CA, Allied Signal Incorporated of Morristown, NJ, and Science Research Laboratory Incorporated of Somerville, MA have worked with us on the conceptual design of ILSE and on the development of appropriate materials and fabrication techniques. We anticipate increased industrial participation. The program benefits greatly from the participation of university faculty and students. Currently, students from the University of California, the University of Maryland, and Princeton University are involved in research related to heavy ion fusion. A student from the Massachusetts Institute of Technology recently completed his Ph.D. degree in our program. Typically ten to fifteen students are involved in inertial fusion energy research.

During the past year we have refined conceptual designs for ILSE components. Our continuing accelerator research program has developed ion sources, injectors, lenses, accelerating structures, and power supplies that are similar to the components needed for ILSE or for a full-scale fusion driver. Experience with these components gives high confidence that we can design and build the ILSE components. In addition, computer modeling of accelerator systems and beam behavior has greatly improved during the last year. Finally, the discontinuation of the Bevalac experimental program at LBL has opened a new site for the ILSE accelerator. The new site leads to lower cost and shorter construction time.

The Conceptual Design Report now proposes a 3-1/2 year construction schedule beginning in FY95. The total estimated cost of construction is $44.0M and the total project cost is $53.3M. The required ILSE funding rate for FY95 through FY98 is approximately $12M per year. In addition, a base IFE program consisting of accelerator theory, small scale experiments, and reactor research requires an addition $8-10M per year. The total IFE funding requirement is $20-22M per year ($19M per year in FY93 dollars) for the next five to seven years. For reference, I note that the FY93 budget for IFE is $7.7M, and that our guidance for FY94 is only $4M.

The IFE program, with ILSE as its cornerstone, has received uniformly positive reviews and strong endorsement from the Fusion Policy Advisory Committee (FPAC, 1990), the National Academy of Sciences (NAS, 1990), and most recently, the Fusion Energy Advisory Committee (FEAC, 1993). FPAC considered four different budget levels for inertial fusion. At the lowest level, FPAC [1] stated, "Even in this low-funding scenario, we recommend beginning the ILSE program and continuing the OFE reactor studies program." The NAS report [2] states, "We concur with the FPAC outline of the most promising path to an energy option, which recommends demonstration and evaluation of driver technologies that have the potential of satisfying reactor requirements, specifically an enhanced heavy-ion driver research program and, with lower priority, KrF and light-ion drivers." The FEAC report on IFE is currently being transmitted to the Department of Energy. The report conveys the recommendations formulated at the April 15-16, 1993, FEAC meeting. The report states that ILSE has high technical merit and is an essential proof-of-principle experiment for heavy-ion drivers. It recommends that a balanced program be maintained, and strongly urges that support be found for this program. The report notes that the ILSE program leverages the investment by Defense Programs.

In summary heavy ion fusion is a promising fusion energy option. The next step, the ILSE Program, has been favorably reviewed by several committees. I believe that the heavy ion fusion program is a sound scientific endeavor. With your support we anticipate success. I would be happy to answer any questions.

References

1. Fusion Policy Advisory Committee, Final Report, U.S. Department of Energy Report DOE/S-0081, September 1990

2. Review of the Department of Energy's Inertial Confinement Fusion Program (September 1990), copies of this report are available from Naval Studies Board, National Research Council, 2101 Constitution Avenue, Washington, DC 20418.

3. Fusion Energy Advisory Committee Report on the Inertial Fusion Energy (IFE) Program, May 1993.

Mr. SWETT. Thank you very much, Dr. Berkner.

We'll now hear from Dr. Maglich.

Dr. MAGLICH. I'm Bogdan Maglich. I'm chief scientist for the Advanced Physics Corporation, which is a lead member of a USA-Russia research consortium, acronymed SAFE, which stands for System for Aneutronic Fusion Energy. "Aneutronic" here means a type of fusion that does not use radioactive fuels, that uses nonradioactive fuels, that has 100 times less neutron radiation, that has 1,000 times less radioactive waste, and that has two to three times less heat pollution than the convention fusion. Our research consortium has 12 member organizations. The American industrial organizations of General Electric and some others are not paid by us. They are not selling anything to us. They are using their own funds for research. So their participation is real.

Mr. Chairman, I will first state how our research consortium sees the DOE's nuclear energy programs in the post-Cold War era and then make three proposals.

The DOE's programs in both fission and fusion were born in the height of the Cold War and their goals were dictated by security requirements. No thought was given to the ultimate commercial embodiment and consumers' needs, and it is no surprise that both programs have encountered severe difficulties in the civilian realm.

We submit here that DOE should gradually do away with the military-inspired technologies of 40 years ago and should stimulate the conversion of American research talent to post-Cold War fusion energy technologies that have been conceived with purely peaceful purposes, consumer and market demands in mind, and are environmentally, economically, and politically acceptable to the American people.

The U.S. fusion program began in deep secrecy as Project Matterhorn and it was inspired only by one idea: by the discovery or by the concept that tritium-based fusion would be the most prolific source of neutrons that could be used to generate weapons-grade fissile materials at far lower cost and far greater quantity than had ever been believed for fission reactors. Therefore, proliferation of nuclear weapons was the initial motivation of the current fusion program.

Large development programs, as it's well known, acquire a life of their own. They acquire institutional and psychological momentum and change much more slowly than our understanding of the facts. Over the past 30 years, and particularly in the past 10 years, it has been increasingly clear that the problems associated with tritium-based fusion will be unsurmountable in a commercial device. Our plans will use radioactive fuel, radioactive waste. They need two fuels that are very often omitted: highly toxic beryllium, highly flammable lithium, enormous complexity-wise, and because of the low power density very expensive per unit of electricity generated.

Tokamak could be made only marginally economical only if it breeds and sells plutonium, which is incompatible with the U.S. nonproliferation policy. No utility wants this device. No naval propulsion system for ships wants it. There is no way of having mobile propulsion with such a device. And if all nuclear plants of the same

Mr. SWETT. Thank you very much. You have provided us with a wealth of information. I know that many of the members will want to follow up with questions, but, in the interest of time and getting everyone's testimony out, I appreciate your concluding quickly and allowing Dr. Storms his opportunity to make his testimony.

Dr. STORMS. Mr. Chairman, I want to thank you for this opportunity to present new and important results about a phenomena that has been conventionally called cold fusion. Starting with the work in 1989 by Drs. Pons and Fleischmann, many observations have indicated that it is apparently possible to initiate nuclear reactions in certain metals near room temperature and that these reactions result in significant heat production as well as various low-level nuclear products. This is in contrast to what we have been hearing earlier with regard to hot fusion, which requires very high temperatures in a plasma.

I'm not speaking today for the Los Alamos National Laboratory on this subject because the policy in this area has not been formulated, and the laboratory does not want me to pre-empt this process. Nevertheless, a careful and extensive examination of available information, as well as personal research, has convinced me and many other scientists that this phenomenon is real and I believe may have important consequences to the United States.

Much skepticism and frustration resulted from lack of reproducibility during early experiments. For this and other reasons, many scientists still believe that positive results are not possible. However, the phenomenon is now reproducible using a variety of techniques. Excess heat production has occasionally approached useful levels, and many positive results are now described in a variety of peer review scientific journals and conference proceedings.

In fact, the information, the evidence is now so persuasive that it has caused the Electric Power Research Institute, EPRI, to support the work at the rate of $4 million a year at SRI and at Texas A&M University, where positive results have become increasingly reproducible.

A company called Technova in Japan is sufficiently impressed by the evidence to equip a large laboratory in France for the use of Drs. Pons and Fleischmann. They can now produce power densities that are ten times those produced by a nuclear power reactor. This means that the rarity of palladium is no longer a problem and that such reactors, such sources of heat, will be relatively compact.

A growing number of companies in the United States are showing interest in the field. Interest in India, China, Italy, and Russia is expanding. The increasing number of positive results, as well as new ways to initiate the reaction, have been reported. Support is especially strong in Japan, where MITI has recently committed $24 million to be added to other larger sources of funding. Indeed, Japan is now leading the field in understanding this remarkable phenomena. We are once again in the position where a major discovery made in the United States is being developed in Japan.

If this were just another example of conventional science being slow to accept new ideas, you might be well advised to wait for nature to take its course. However, I believe this phenomena is of such potential importance that it would not be prudent to wait. I may not be able to convince you of these conclusions in this brief

Mr. SWETT. Thank you very much, Dr. Storms.

We have 10 minutes until a vote. I would like to get the testimony of Dr. Mills on the record before I adjourn for the vote. We have a 15-minute vote and then a 5-minute vote. I will return myself for questioning. I hope that that does not put a crimp in anybody's schedule.

Please continue with your testimony and let's try and get that on the record as quickly as we can.

I assume I can sprint over with five minutes. Any members who need to leave prior, certainly I understand their requirement due to their slower athletic ability. [Laughter.]

Dr. MILLS. Thank you, Chairman Swett, for having me here. It's an honor to present in front of this Committee.

I have a number of documents that I've provided staff with that I'd like to be made a part of the record along with my testimony.

Mr. SWETT. Without objection, so ordered.

Dr. MILLS. HydroCatalysis Power Corporation has had a long-running extensive theoretical and practical experimental program in the development of energy from light water electrolytic cells. We're using ordinary water, not heavy water. I have with me a representative of Thermacore, Incorporated, with which we have a joint development program to produce a commercial product. If there's any questions for Thermacore, they can be addressed to Bob Shaubach, which I introduce now.

All our demonstrations—HydroCatalysis Power Corporation I'll refer to as HPC. HPC and Thermacore, at the present time all our demonstration cells, with 100 percent reliability, produce excess heat immediately and continuously. We've had cells that have gone up to a year and are still running at the present time that produce 50 watts and greater of power, which represents a billion joules of new energy. The power yields that we have been able to achieve have been as high as 10 times the power out relative to the total power in.

The power is not from a nuclear fusion reaction. All indications that we have is that what we're seeing is the formation of a new form of hydrogen, a new chemical form of energy, represented by the work that we are doing. This new form of hydrogen we have identified in nature, and we have currently confirmatory and verification studies ongoing that have identified in the lab the new form of hydrogen that is a product of our electrolytic cells.

Well, of course, the applications I think are very obvious. Basically, what you're looking at is a new form of energy, a new form of chemical energy, that's essentially in enormous abundance, essentially inexhaustible, nonpolluting, and very, very inexpensive. The equipment involved is comparable in cost, from our projections, of what fossil fuel equipment is at the present time, without any of the containment, confinement, or radioactive waste disposal problems or any of the problems associated with fossil fuels, be it the pollution, acid rain, et cetera.

There are two major impediments to the acceptance of the technology. One has to do with its association with the area of cold fusion, and they're actually related. It turns out if we use heavy water, we can produce in our experiments very, very trace, minus-

Mr. SWETT. Let me go make this vote. We will reconvene. I'm going to adjourn the hearing for the time necessary for this vote and the possible second vote afterwards. Please stay seated. We'll be—well, stay in the local area; don't stay seated. We'll be back as quickly as we can.

[Recess.]

Mr. SWETT. I'd like to reconvene the hearing.

We have at least two members who are here who are interested in asking some questions, and I hope that it won't take too much of your time, but it might be helpful in drawing out a few more bits of information that will add substance to already a fairly substantial record.

I would like to start out by asking every member on the panel what they see the funding necessary for their particular area of exploration and expertise would require in order to move the science off the dime and into an active mode toward accomplishment. And I think that, first, I'll just ask you to go down the line and give your answers in relation to what you're currently receiving from DOE or other entities in the government.

Dr. Berkner?

Dr. BERKNER. In the heavy ion fusion program, the Fiscal Year 1993 budget is about $8 million. The line that's in for 1994 is $4 million. To do the program that the Fusion Energy Advisory Committed recently recommended is a $20-million-a-year effort.

Mr. SWETT. OK.

Dr. BERKNER. So, you see, today we're down 2.5. As of next year, we'll be down by a factor of five.

Mr. SWETT. OK, thank you.

Dr. Maglich?

Dr. MAGLICH. Yes. Our program calls for $30 million over a period of three years, then increasing, but——

Mr. SWETT. Is that an even 10, 10, and 10 distribution or——

Dr. MAGLICH. Yes, but, actually, we have requested from DOE only $17 million. The balance would come from the industry. In other words, about 40 percent would come from industry.

Mr. SWETT. OK. Dr. Storms?

Dr. STORMS. Well, in our case the official contributions from the government or the DOE are zero. And so any bit would have a big impact.

Contributions from outside sources—industry, EPRI, and whatever—are probably in the neighborhood between $5 and $6 million. So I would suggest something in the neighborhood of $10 million would be a significant improvement in the present situation and have a big impact without having a serious impact on other programs.

Dr. SWETT. I don't recall in your testimony—refresh my memory—what is the level of investment that other countries are placing in that technology at this time?

Dr. STORMS. Japan is putting in the largest amount. It's very difficult to estimate a total. We know that $24 million from MITI. But there are also broadly-based programs being supported by industry, and the universities have discretionary funds. It could be as high as $100 million, perhaps even a little higher than that.

Other countries, again, it's very difficult. India is putting significant money at their Bhabha Atomic Energy Establishment. I don't know how to estimate that. There are probably 50 to 75 people working on the field there.

Italy has a small program. There are probably maybe 50 people working in Italy at the present time.

It's not a big program worldwide, but it's increasingly active. And those who are in the field and are aware of the implications of it feel very strongly that we need to do something to not fall too far behind.

Mr. SWETT. Dr. Mills?

Dr. MILLS. I've been solicited by a number of national labs and academic institutions who would like to work on this. There are people that have reviewed this. There's 20 different places that I've been to and spoken, and we have some institutions that have already done pilot projects, but there's no money available, ear-tagged, for this at all, zero. And we've——

Mr. SWETT. So you're in the same boat as Dr. Storms at the present——

Dr. MILLS. The money——

Mr. SWETT [continuing]. With no money from the Federal Government?

Dr. MILLS. No funding from the—this is all private funding, and we feel at this point that we're very close, about 95 percent of having those four items—the theory, the product, the reaction, incontrovertible heat demonstration device and identification in nature—done on our own funds. All we need is to have to warrant a large research development program, to push it toward commercialization, is to involve the academic labs and have them cooperate. And there is an existing CRADA program to do that, and we have people right now at this moment who would immediately initiate such a program, if there were funding available.

And the funding level that they anticipate in collaboration with me on what it would take to get it substantially reduced to practice and very close, certainly within five years, maybe within one year of having a commercial boiler demonstration, is on the order of $1 to $5 million, depending on the scope of the project.

Mr. SWETT. We'll go back in the other direction on the second round because I'm very interested in getting a comparative array of answers to questions from all of you.

My next question is sort of a follow-on to what Dr. Mills was talking about, and that is, if you could estimate—and I understand that these are estimates only and certainly should not be looked on as anything more than that—how much time it would take to bring the various technologies that you represent to some kind of commercial viability or at least to ascertain its potential so that the pursuit of that technology would eventually be realized in a commercial setting? Dr. Mills?

Dr. MILLS. We've already demonstrated we could produce steam with the process, and at power levels that are approaching very commercially viable and interesting levels. The cost now has been reduced, with the new materials we're using, on the order of—they're essentially pennies per watt. So we've gotten the material costs under control. We've gotten the power levels there, and we've gotten the power ratios. The main thing we have to do is demonstrate the viability of the technology, show the community at large—because even private funding kind of warrants there to be a consensus that this revolutionary technology is really real. People don't want to put money into something unless they have the experts sign off on it.

So, from our perspective, what we really would like to propose is that the government just cooperate, the national labs cooperate, in letting us bring the technology there and have them also replicate it and take independent measurements of it.

Beyond that, we've already gone over a program with the national lab on what it would take to get a boiler demonstration that could be used to take measurements for commercial products from, and that's something on the order of a six-month-to-year project, probably somewhere between half a million and a million dollars.

Mr. SWETT. How much time would you project before this becomes a commercial entity?

Dr. MILLS. Certainly within five years, and we probably could have some sort of premanufacturable prototype within a year's time.

Mr. SWETT. Dr. Storms?

Dr. STORMS. Well, you—we've just watched the Wright brothers take off and you're asking me when I can build a 747.

Mr. SWETT. Well, we've watched the Wright brothers and we've watched any number of other experimental things take off. So I know I'm asking you to project a little bit further than you might otherwise feel comfortable, but if you could take the liberty and understand the qualifications that we're placing around this projection, I'd appreciate it.

Dr. STORMS. I think that given the implications of being able to solve the energy problem with respect to pollution, with respect to the CO2 in the atmosphere, with respect to the energy needs of the Third World, all of these very serious problems that are looking us in the face as major disasters at some point, that there will be a tremendous amount of effort devoted to trying to develop this technology as rapidly as possible, if it will lend itself to that kind of development.

And I would suppose that we would see some serious effort to industrialize it in five years on a small scale; Because it's so important—and Dr. Miles' work also falls into that same category—to solve these other problems; I think a lot of effort will be devoted to developing it quickly.

Mr. SWETT. Dr. Maglich?

Dr. MAGLICH. Yes, our plan has been worked out on several assumptions; that is, that our program calls for three steps. One is the Demonstration of Energy Production experiments: We call that the DEP experiment, which you can see in Figure 4. This is the diagram of progress. If we make this leap from here to here, what we call the energy production is at $30 million, as I said, a three-year program. This should be followed by a $20 million, two-year program to light the bulb, to have a system that generates 1 kilowatt electricity in a light bulb. This will be followed by a five-year, $1.5 billion program.

and I thought I would just be the devil's advocate and present his views and then get reactions. But I gather that most of you would tend to say that the emphasis is much too heavily upon the Tokamak. That seems to baffle me.

And then we're going to be, apparently, enhancing the TFTR and we're going to be building a PTX—is that it? A TPX? We're putting an awful lot of money into it, and then when the ITER comes along, that's going to eat up everything, isn't it? I mean, what's going to be left for anything else out there? And there may be others who have some of these plans.

So I think that your appearance here does give us some of that flavor that we otherwise would not have had, and I would compliment Madam Chairman for having arranged to have you here. And, as I've said, I'm going to spend more time looking at your written testimony, and I appreciate very much your oral testimony.

Yes, Dr. Maglich?

Dr. MAGLICH. An American inventor Firestone, who produced the first pneumatic tire, came to show the tires to the Dunlop Company. Then tires were hard. They told him, "We know it cannot be done."

He said, "I have my car parked downstairs. It has pneumatic tires, air-pumped tires. Please look through the window."

And Mr. Dunlop said, "Please don't tell me it's possible. Our experts tell us it's impossible."

Well, of course, now thanks to this, Mr. Firestone became a rich man. But, by the same token, we have the same situation with DOE. You have here the experimental data obtained from Tokamak showing that the reactor does not have to be large, but, nevertheless, they say, "Don't tell me that. Our experts tell me that has to be large," in other words, denying data obtained by themselves.

It is so typical of an entrenched program that there is no other way but to form a separate division.

Mr. FAWELL. Thank you very much. Again, I appreciate the testimony.

Mr. SWETT. Thank you, Mr. Fawell.

This has been a very inspiring afternoon for me. I have learned a great deal, including the proper pronunciation of one of my colleague's last name. [Laughter.]

But I also learned that he is a pioneer just as you are, and that's something that I did not realize and I now have further discussions that I'm going to follow up with when I have an opportunity to meet with him on the floor during votes.

What we are trying to do, I think, both he and I, you have come to recognize, is get at an attitude shift in the DOE or at least identify how we might establish a very compelling argument to force DOE to recognize the technology that you are engaged in, to legitimize at least significant small amounts of funding to help you to pursue your efforts toward proving that commercial value.

It's probably going to make many more of these hearings, and certainly some of you are already actively engaged in discussion with DOE trying to teach them that you have, if not a pneumatic tire downstairs to show them, drawings and plans that will lead to that pneumatic tire that might ultimately convince them to recognize that it does exist.

My sense is that there is going to need to be very detailed planning on the part of all of these technologies and the scientists involved in them to demonstrate how, as you go down that line month by month, year by year, that the milestones that you can accomplish are measurable and, therefore, provide that kind of visual fact of success, so that this country, as it is locked in a very difficult struggle with finances, can turn around and explain to the taxpayers that that money is not being thrown down a rat hole, but is rather developing good and very progressive technology that in the future is not only going to help the taxpayers, but it's going to help the environment as well.

Those are the things that I offer you as encouragement. I am very grateful for your coming and testifying. You are all in the same boat. I encourage you to work together to foster a little corner of alternative fusion potential within the larger fusion environment at DOE, and, hopefully, with that cooperation and that continued effort, we can realize the funding that will finally put you on the map in the bureaucracy.

Thank you once again and we look forward to hearing from you in the future of your successes.

This meeting is now adjourned.

[Whereupon, at 5:50 p.m., the Subcommittee adjourned, subject to the call of the Chair.]

APPENDIX I

Department of Energy
Washington, DC 20585
June 22, 1993

The Honorable Marilyn Lloyd
Chairman
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Madam Chairman:

On May 5, 1993, Dr. N. Anne Davies, Associate Director of the Office of Fusion Energy, Office of Energy Research, testified before your subcommittee regarding the Fiscal Year 1994 budget request for the Fusion Energy program.

Following the hearing, you submitted eight written questions to supplement the record. Enclosed are the answers to those questions. Additional questions submitted by Congressman Fawell are in the clearing process and will be forwarded to you as expeditiously as possible.

If we can be of further assistance to you or your staff, please contact our Congressional Hearing Coordinator, Barbara Campbell, on (202) 586-8238.

Sincerely,

Elizabeth A. Cecchetti
Acting Assistant Secretary
Congressional, Intergovernmental,
and International Affairs

Enclosures

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 1: Billions of dollars and 30 years have been invested in the development of the magnetic fusion concept. In spite of the progress made, this technology has not yet proved that it can become an economical, reliable, and continuous source of electricity. Why then is it the only fusion option being pursued by the Department?

The Department remains open to considering any ideas on fusion energy. The principles of physics allow only a few approaches to the confinement of very hot gas necessary to produce a fusion reaction. Over the years, various ideas have been proposed to the Department. All proposals are reviewed for technical merit and an attempt is made to conduct research in proportion to that merit. This process has resulted in the present emphasis on the toroidal magnetic approach that is judged, worldwide, to have the highest potential to lead to an economical, reliable, and continuous source of electricity. A substantial effort is also supported within the Department on inertial confinement fusion, in part because of its potential to produce electricity but primarily because of its contributions to weapons research and development. In addition, a solicitation of proposals for new magnetic confinement concepts was recently concluded. The selection process resulted in the choice of three research proposals to receive a total funding of $1.2 million per year for three years. These three experiments will explore concepts quite different from the toroidal magnetic confinement approach. While speculative, these approaches offer some promise of smaller and simpler energy sources relative to the tokamak.

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 2: Why must the Tokamak Physics Experiment proceed now? Why can't the initiation of this facility be deferred, at least until after the deuterium-tritium operations at the Tokamak Fusion Test Reactor? The time dependency for a Fiscal Year 1994 start does not seem to be related to the International Thermonuclear Test Reactor Program because the International Thermonuclear Test Reactor design is obviously ahead (schedule-wise) of the period when Tokamak Physics Experiment could be built and operated and, as such, influence the design of the International Thermonuclear Experimental Reactor. Furthermore, it appears that something might be learned from the deuterium-tritium operations at Tokamak Fusion Test Reactor which could influence some of the design features for the Tokamak Physics Experiment.

By proceeding now with the detailed design for the Tokamak Physics Experiment, the machine could be operating by around the year 2000. It would provide at least 5 years of experimental results before the International Thermonuclear Experimental Reactor could come into operation. It was never intended for the Tokamak Physics Experiment to influence the design of the International Thermonuclear Experimental Reactor, which is based on conservative extrapolations from the present experimental data base. It could, however, substantially influence the operating techniques for both the basic and enhanced performance testing phases of the International Thermonuclear Experimental Reactor. Of even greater importance is the need to have a vigorous domestic fusion program in order for us to be a credible partner in the design and construction of the International Thermonuclear Experimental Reactor, and for us to take full advantage of the information gained in operating the International Thermonuclear Experimental Reactor. In addition, by starting the Tokamak Physics Experiment at this time, United States industries will benefit from the Tokamak Physics Experiment construction experience in preparation for bidding on work packages for the International Thermonuclear Experimental Reactor construction.

Programmatically, the mission of the Tokamak Physics Experiment is independent of the Tokamak Fusion Test Reactor deuterium-tritium experiments and complementary to the International Thermonuclear Experimental Reactor. The Tokamak Physics Experiment is intentionally aimed beyond the International Thermonuclear Experimental Reactor toward development of advanced physics modes that could lead to a more economically attractive demonstration reactor. The deuterium-tritium experiments on the Tokamak Fusion Test Reactor would have negligible impact on the design of the Tokamak Physics Experiment. Hence, there is no reason to wait for the Tokamak Fusion Test Reactor deuterium-tritium results, which will be more germane to the International Thermonuclear Experimental Reactor's burning plasma physics mission objectives.

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 3: How can the potential for a heavy ion inertial fusion facility ever be realized or rejected if there is no consistent program directed toward the economical production of electricity using this technology? It would appear to be much too early to rule out this option; so the question is, why is this technology being dropped, through the cancellation of the Induction Linac Systems Experiment, by the Department? As an investment strategy, it would seem less risky to spread the resources over at least two, and possibly more, fusion energy options.

Inertial fusion has not been ruled out as an energy option. The most critical issue, obtaining and characterizing laboratory ignition, is the goal of the inertial confinement program that is funded by the Defense Programs part of the Department. Because of efficiency, repetition rate, and flexibility, the heavy ion driver approach is the most likely way to lead to energy applications of inertial fusion. Realizing the potential for heavy ion inertial fusion will require a significant and sustained effort. The heavy ion driver is not ready for full scale deployment today, but could be by about the time that laboratory ignition has been achieved. The Department has not canceled the Induction Linac Systems Experiment that represents an attractive approach to establishing the feasibility of the heavy ion driver concept. The Induction Linac Systems Experiment has been delayed because of budget constraints and an uncertain schedule for achieving a laboratory ignition demonstration.

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 4: In Dr. Robert Conn's letter of May 4, 1993, to Dr. William Happer, Dr. Conn, as Chairman of the Fusion Energy Advisory Committee, mentioned a number of considerations pertaining to the Heavy Ion Inertial Fusion. These considerations included the following:

-- The Department has not established an Inertial Fusion Energy program that resembles the one envisioned by Dr. Guy Stever for the Department in 1990.

-- The Induction Linac Systems Experiment has high technical merit and is an essential proof-of-principle experiment in demonstrating the induction linac as a heavy ion driver.

-- With regard to program funding, the letter stated: "In the low ($5 million) case, there is no creditable program for the development of a heavy ion fusion energy option. The base accelerator and physics program in this case continues some of the core accelerator research activities but does not provide any significant advances in large-scale demonstrations."

-- "During our meeting of April 15 and 16, the Department informed the Fusion Energy Advisory Committee that the proposed Fiscal Year 1994 budget for Inertial Fusion Energy in Energy Research is $5 million, i.e., less than the lowest case you asked us to consider."

Question 5: Given the above, the $4 million allocation for Heavy Ion Inertial Fusion appears to represent a defacto project cancellation. Is that the intent of the Department?

That is not the Department's intent. We are currently considering the advice from the Fusion Energy Advisory Committee on heavy ion inertial fusion. The $4 million request for this program in Fiscal Year 1994 was submitted prior to receipt of the committee's advice. The $4 million request is intended to sustain the program while its near-term future is under consideration. Decisions on how to proceed with the inertial fusion energy program are part of the deliberations on the Fiscal Year 1995 budget.

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 6: Public Law No. 102-486, Section 2114, Fusion Energy, October 24, 1992, clearly calls for a "broad-based fusion energy program." Is the Department's interpretation of "broad-based" one that limits the development to one single technology, i.e., Tokamak reactors?

The Department's interpretation of "broad-based energy program" is not one that limits the development of fusion energy to one confinement approach. The Department is pursuing both the magnetic and the inertial approach to the development of fusion energy. Within the magnetic portion of the program, many different confinement approaches have been investigated over the years including tokamaks, tandem mirrors, dense z-pinches, stellarators, torsatrons, heliotrons, theta pinches, and reversed field pinches. Currently the United States program has been focused on the tokamak concept because it is the leading approach and fiscal constraints do not allow us to make significant progress on multiple confinement concepts.

The tokamak is the major focus for all of the world's major fusion programs. This is based on numerous, cumulative accomplishments in advancing physics understanding and developing related hardware and engineering systems. The European and the Japanese program funding constraints are less severe and they are thus able to expend some of their resources in developing other confinement concepts. The United States stays abreast of their developments through the expenditure of small amounts of money that allow United States researchers to participate in collaborative programs with these two entities. Within the inertial approach, again, funding constraints and technical reviews have kept us from exploring fully other possible alternatives to the heavy ion program.

We have recently initiated a new program that explores new confinement systems approaches. Approximately 3.5 percent of the fusion energy budget is currently being spent on non-tokamak, magnetic confinement research, and 2 percent of the fusion budget is spent on inertial fusion energy research.

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 7: Public Law No. 102-486 also provides for research and development for Inertial Confinement Fusion Energy and development of a Heavy Ion Inertial Confinement Fusion experiment. In spite of that, Volume II of the Department of Energy's Fiscal Year 1994 budget contains the following statement: "A decision has been made not to proceed with the construction of the Induction Linac Systems Experiment accelerator in Fiscal Year 1994." Is it the Department of Energy's intent to drop the Inertial Program and, if not, what is the Department's intention?

It is not the Department's intent to drop the inertial fusion program. The Department decided not to recommend initiating the Induction Linac Systems Experiment accelerator in Fiscal Year 1994 because of budget constraints and some uncertainty in the schedule for the primary inertial fusion activity funded by Defense Programs. The inertial fusion program, including the Induction Linac Systems Experiment facility is currently under discussion in the Department following the Fusion Energy Advisory Committee's recommendations on the program and in preparation for the Fiscal Year 1995 budget.

QUESTIONS FROM REPRESENTATIVE LLOYD

Question 8: Public Law No. 102-486 also called for a "Management Plan" for fusion energy to be delivered within 180 days. The Committee notes this plan has been delayed until October, 1993. How can work proceed efficiently in the development of fusion energy in the absence of a plan?

The Department has developed a Multi-Year Program Plan for fusion energy. This plan contains the program's goals, and the plans for reaching these goals. The plan is currently undergoing revision to reflect the ongoing budget process. This multi-year plan will form the basis for our response to the requirement contained in Public Law No. 102-486.

ITER EDA
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INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR • ENGINEERING DESIGN ACTIVITIES

2 July 1993

Hon. Harris W. Fawell
Ranking Republican Member
Subcommittee on Energy
House Committee on Science, Space,
and Technology
H2-390
Washington, D.C. 20515

Dear Congressman Fawell:

I appreciated the opportunity to testify before the Subcommittee on Energy regarding the progress of the International Thermonuclear Experimental Reactor project.

Per your request, enclosed herewith are my responses to your written questions.

Please do not hesitate to contact me should you have any additional questions to raise.

Sincerely,

Paul-Henri Rebut

JVF:mac
Enclosure

International Thermonuclear Experimental Reactor Engineering Design Activities conducted by the European Atomic Energy Community, Japan, the Russian Federation and the United States, under the auspices of the International Atomic Energy Agency

P.-H. Rebut
Responses to Follow-up Questions
from the Subcommittee on Energy
Hearing on Fusion Energy
May 5, 1993

1. In Mr. Fawell's opening statements, he made reference to the remarks by Dr. Robert L. Hirsch at the March 5, 1993 meeting of the DOE's Fusion Energy Advisory Committee (see attachment).

a. Please comment on Dr. Hirsch's observation that deuterium-tritium (DT) tokamak and laser-fusion reactors as currently envisioned will be extremely complex, highly radioactive, likely to be highly regulated, and costly.

Answer: It is certain that a fusion reactor is complex and involves many technologies, but I believe that it will be no more complex than the development, for example, of space technology.

In terms of radioactivity, I disagree with Dr. Hirsch that a fusion reactor will be highly radioactive. By using advanced materials, like Lithium, Beryllium, and Vanadium, the activation will be at a low level (Vanadium).

I am persuaded that the cost envisaged for a fusion reactor will be competitive with other large-scale energy supply sources especially if you include the costs (direct and indirect) associated with the impact on the environment of energy production.

It is difficult for me to comment on regulatory issues, since they are nonexistent for fusion and could be potentially different in each country. However, I intend to work with the regulatory agencies when a construction site has been identified and provide them with all information they may need to establish regulations for fusion.

1b. Please comment on Dr. Hirsch's observation that even if DT or laser fusion reactors had the same capital costs as a fission reactor — an enormous challenge — fusion reactors would lose out to advanced fission reactors, which are a reliable, known quantity.

Answer: I do not believe that fusion will lose out to fission, but that these will be the only energy supply technologies capable of meeting energy demand in the future. And I am not certain that fission reactors are perceived today as a reliable and known quantity.

1 c. Please comment on Dr. Hirsch's observation that none of the very few fusion-knowledgeable utility people he had spoken with believes that tokamak or laser fusion reactors, as currently envisioned, would be acceptable to the electric utilities.

Answer: Current generation tokamaks are experimental physics machines. The reactor will be simpler because it will work in a defined regime. A reactor will only require a few people to operate, as demonstrated at the Joint European Torus. In the end, the overall cost of electricity will be the major element of decision for electric utilities, including the cost linked to the environment.

1 d. Please comment on Dr. Hirsch's observation that there are some enormous materials problems related to DT fusion. There are no qualified materials today for DT fusion reactors. In the absence of development of a low activity material — a very costly and time consuming undertaking — you will have to effectively rebuild your fusion reactor every 5-10 years and dispose of many times the amount of radioactivity that would come from a fission reactor of the same power level.

Answer: It is certain that new materials will need to be developed, just as new materials were developed to advance technologies such as fission, aeronautics and astronautics, as well as more familiar objects like cars and tires.

A database already exists for the advanced materials that we are planning to use in ITER; these materials will have a minimum level of activation.

To say that we will need to rebuild a fusion reactor every 5 to 10 years is an exaggerated statement. In an extreme case, we may need to replace only the first wall of the reactor after 10 years. The first wall represents a few percent of the overall machine. But in the best case, the first wall could be replaced after 30 or 50 years, which is essentially equivalent to the full life-time of the reactor.

1 e. Please comment on Dr. Hirsch's observation that if tokamak reactors, as currently envisioned, aren't acceptable, can ITER be possibly justified?

Answer: The tokamak is the most promising system in the fusion field. But even if another magnetic configuration is chosen most of the problems that will be solved with ITER are common to all magnetically-confined fusion devices.

1 f. Please comment on Dr. Hirsch's observation that if you build ITER, it will become the flagship of fusion and will likely eliminate the chance of serious funding for alternate concepts.

Answer: I have always advocated the continuation of a base program in parallel with ITER. If a more attractive solution develops we hope to incorporate it into the ITER device.

1 g. Please comment on Dr. Hirsch's observation that if what ITER represents is seriously considered in public debate, there is high probability that ITER will not be supported and the fusion program could collapse.

Answer: Energy is a long-term problem and the general public needs to be provided with factual and balanced information on these issues. If we want everyone in the world— including the lesser developed countries — to enjoy a minimum level of energy — that is at least a minimum standard of living — in my view, only fission and fusion can fulfill the energy demand.

I believe that, at this time, the public is basically unconcerned about energy issues in general because past shortages and high energy prices have escaped their memory. At the same time public concern has increased about the environmental impact of burning fossil fuels and the long life of nuclear waste. There is a responsibility on the part of the world's leaders to have a long-term view on the demand for energy. In a peaceful time, it seems rational to direct a small fraction of the research effort towards providing "clean" energy to everyone.

1 h. Please comment on Dr. Hirsch's recommendation that scale-up of alternate R&D concepts proceed as fast as possible.

1i. Please comment on Dr. Hirsch's recommendation that tokamak or laser fusion not be stopped but cut back and reoriented in more acceptable directions.

Answer: Yes, if alternate R&D concepts are more promising than the tokamak they should be scaled up as fast as possible, but their promise must be demonstrated in theory and justified scientifically. This does not mean that R&D on the tokamak concept should be scaled back.

1j. Please comment on Dr. Hirsch's recommendation that we get off the DT fuel cycle to avoid frequent reactor reconstruction, large quantity radwaste disposal, and expensive materials development.

Answer: At the present state when the D-D "aneutronic" fusion reaction is compared to the D-T reaction, at least an order of magnitude is missing in the plasma confinement.

2. You mention the need for an intense neutron source to test the durability of materials. What would be such a source and what might it cost.

Answer: The device would be a driven source directing high energy particle beams at a target to produce 14 MeV neutrons. The cost could be roughly $1B.

3. What is the benefit to ITER of the current US tokamak programs? Is the continued operation of these necessary for the ITER design effort, or do you already have sufficient data?

Answer: ITER is the culmination of results and achievements from the four Parties' fusion programs. In my testimony I have already mentioned the role of DIII-D, which has a geometry similar to ITER. Now there are large endeavors to be undertaken relative to the divertor and operation of machines with D-T. Thus, the DIII-D and TFTR experiments are important to the ITER project. A strong overall US domestic program is also important to the success of the ITER project.

4. Please comment on the role of the current EC, Japan, and Russian magnetic fusion energy programs on the ITER design.

Answer: The domestic programs of all four Parties are required to support ITER and are important to its overall success. By pooling the knowledge and the resources of the four Parties, I am confident that we will achieve the objectives of ITER.

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MEMO TO: Dr. Harlan L. Watson
Subcommittee on Energy

MEMO FROM: Dr. Ronald C. Davidson *Ronald C Davidson*

SUBJECT: Congressional Questions

DATE: June 22, 1993

Congressman Harris Fawell submitted additional questions for my response in order to supplement the Subcommittee on Energy hearing record from May 5, 1993. Attached are my responses to these questions. Please feel free to contact me at 609-243-3553 if you need any additional information.

Congressional Questions
Response to Mr. Fawell

Q.1.a. Will D-T fusion reactors as currently envisioned be extremely complex, highly radioactive, highly regulated, and costly?

A.1.a. Design projections of fusion reactors indicate that they will indeed be complex, although probably no more difficult to operate than existing electric power plants of similar size. The radioactivity of a fusion reactor will depend on the materials from which the reactor is built because the fusion process itself produces no radioactive products, unlike the fission process. The hazards from radioactive wastes (based on volume, toxicity, and longevity) are expected to be thousands of times smaller than from fission plants. The regulations applied to fusion plants and other energy sources of the next century are difficult to predict. However, I expect that fusion will be given credit for its relative safety. For example, it should be possible to design fusion reactors so that no credible accident could produce prompt fatalities at the site boundary. Several studies have examined the cost of fusion power based on reasonable extrapolations from present systems, and they estimate the cost of electricity to be in the mid-range of various methods of producing electricity. For example, the recent ARIES study centered at UCLA under Professors Conn and Najmabadi, estimated the cost of electricity from fusion at about 5.7-7.7 cents per kilowatt-hour, compared to 6 cents per kilowatt-hour for advanced coal and 5.7-9.5 cents per kilowatt-hour for nuclear fission power. [For details see the report of the Senior Committee on Environmental, Safety, and Economic Aspects of Magnetic Fusion Energy (ESECOM), U.S. DOE, 1989; and "Safety and Environmental Aspects of Fusion", in Annual Reviews of Energy and Environment, 1991; by Prof. John Holdren, Chair of ESECOM; and the ARIES Tokamak Reactor Study, UCLA, 1991, 1993.]

Q.1.b. Would fusion reactors lose out to advanced fission reactors, even if they had the same capital costs, because fission reactors are a known quantity?

A.1.b Fusion shares with fission advantages over fossil fuels with respect to emission of atmospheric contaminants and greenhouse gases. Beyond that, fusion offers inherent advantages over fission with regard to plant safety, hazards of radioactive waste, resistance to weapons proliferation, and availability of fuel. The regulatory climate and the public demand for environmental measures are difficult to predict two decades into the future. I expect, though, that fusion would be an attractive choice. It is worth remembering that none of the non-fossil choices--including advanced fission and renewable sources--have yet been demonstrated on anything close to the scale that will be required. Given the tremendous disruptions that would result from having insufficient energy, it surely would be prudent to develop now all the alternatives that appear attractive.

Q.1.c. Would fusion reactors be acceptable to electric utilities?

A.1.c. Utilities are concerned with immediate generation of electricity, not generally research and development. Others develop the new technologies. As Harold Forsen and several of us testified before your committee, it is significant that several leading engineering design firms that build the plants for utilities to operate have participated in advisory panels that have given fusion its current direction and are involved in fusion development. Evidently, they believe that the current path of development is leading toward a product they could build and support.

Q.1.d. Are there no qualified materials available for building D-T fusion reactors?

A.1.d. Fusion reactions take place in a neutron-rich environment. It is important that fusion reactors be constructed from materials that can retain their structural strength and not contain elements that have long-lived radioactive forms. Furthermore, some portions of a reactor, such as the divertor, are likely to be exposed to high heat fluxes. These present difficult challenges to materials scientists. In some cases it is a matter of new application of existing materials to fusion devices; in other cases it will require significant further development and testing to qualify materials for fusion. Advisory committees and experts in the field have called for an enhanced program to develop and qualify materials, but they do not see insurmountable problems.

Q.1.e. Can ITER be justified if, as Dr. Hirsch asserts, tokamaks are not acceptable.?

A.1.e. I do not share Dr. Hirsch's view that tokamaks as currently envisioned are not acceptable candidates for practical fusion reactors. Fusion planners around the world believe that the first generation of practical fusion reactors will use the tokamak concept and, as such, will have distinct advantages over nuclear fission plants and other means of electricity generation. An engineering test reactor like ITER has been identified for many years by fusion scientists around the world as an essential step toward a practical fusion reactor.

Q.1.f. Will the construction of ITER draw funding away from the study of alternate concepts?

A.1.f. ITER is one essential part of the full fusion development program. ITER should not be allowed to displace other essential parts of the program. In the coming decade, following TFTR's landmark high-power experiments with deuterium and tritium and construction of TPX and ITER, the public will begin to see fusion as a real possibility for addressing the worldwide energy problem. As it is perceived to be approaching practicality, fusion will start to receive resources appropriate to its great promise and to the pressing global need for environmentally attractive alternatives to fossil fuels. Progress toward practical fusion power--including construction of ITER--will result in more, not less, attention to perfecting fusion science and technology. I do not believe that consideration of promising alternate concepts will suffer.

Q.1.g. Would public debate lead to the rejection of ITER?

A.1.g. As I have stated above, an engineering test reactor like ITER has been recognized for many years by fusion scientists as an essential step. I believe it will be seen by the public as a large step toward practical fusion power and thus will engender support and enthusiasm for the fusion development program.

Q.1.h. Should we scale up alternate R&D concepts as soon as possible?

A.1.h. There is widespread agreement throughout the world fusion community and from numerous advisory committees that the tokamak concept is the most promising avenue toward practical fusion power. Of course, as in any field, good alternative ideas should be explored, but in times of constrained funding it is wise to concentrate on the most promising path. Along the tokamak path, there are many possibilities for improvement. For example, the Princeton Beta Experiment-Modification (PBX-M), the Doublet Tokamak (DIII-D) at General Atomics, and the Tokamak Physics Experiment, are all directed toward improvement of the tokamak concept.

Q.1.i Should tokamak and laser fusion research be cut back and reoriented?

A.1.i. The fusion development program based on the tokamak concept is the result of thorough, repeated planning exercises. It is well directed, and its progress is limited primarily by funding. For the sake of this country's economic and environmental well being tokamak fusion research and development should be accelerated, not cut back. As for laser fusion, it is being pursued, on a scale much smaller than that of magnetic fusion, for a variety of reasons, one of which is its possible use as an energy technology.

Q.1.j. Should fusion research get away from the D-T fuel cycle?

A.1.j. Fuel cycles other than deuterium-tritium mixtures (D-T) present much greater problems for creating the physical conditions in which fusion will occur. There are several considerations in selecting a fusion fuel, including the fuel availability, cross section (probability) of two particles fusing, the temperature required for the fusion to occur, and the energy produced in each reaction. Deuterium-tritium reactions offer distinct advantages over other nuclear fusion reactions with respect to these characteristics. As stated above, the radioactive waste resulting from the D-T fusion will present much smaller hazards than that from fission plants--that is, thousands of times less. Other fuels proposed for fusion reactors also produce neutrons and can activate the reactor and so are not entirely free of radioactive waste. D-T fusion is achievable and environmentally very attractive compared to other non-fusion alternatives. Compared to D-T fuels, other fusion fuels are very difficult to obtain, much more difficult to use, and not entirely clean. Although ultimately there may be advantages to using non-D-T fuels, I see no reason to depart from the D-T path now.

Q.2. In his opening remarks, Mr. Fawell expressed concern about the role of, and the need for, a new proposed tokamak device, TPX, for which the DOE budget documents provide neither a cost estimate, a time schedule, nor an understandable rationale of why it is so important. Please address these concerns.

A.2. Several parallel and essential paths of R&D are required for building an economically attractive fusion power reactor. These include the attainment of high fusion power on a reactor scale from self-sustained burning plasmas, and the development of approaches for continuous and advanced modes of operation. The former is the primary mission of the International Thermonuclear Experimental Reactor (ITER), while the latter is pursued in PBX-M and DIII-D, and other tokamaks, and will be pursued in the Tokamak Physics Experiment (TPX).

The TPX mission is to develop the scientific basis for a compact, economical, and continuously operating tokamak. TPX, scheduled to operate 5 years in advance of ITER, will for the first time introduce certain critical fusion technologies into the tokamak, giving considerable experience to U.S. industry and enhance their competitiveness in ITER. These critical technologies, also used in ITER, include advanced superconducting magnets, robotics for remote maintenance, internal nuclear shielding, low activation vacuum vessel materials, plasma controls for steady state operation, and steady heat-removal technologies.

The proposed TPX project has recently undergone a very successful Conceptual Design Review by an international team convened by the Department of Energy. The project has also undergone a very successful DOE-directed Independent Cost Estimate (ICE) review. The cost estimate for TPX (after account is taken for recommendations from these reviews) is $530M in FY 93 dollars and $618M when these costs are escalated through the years of expenditure. The scheduled date for completion of construction of the project and the beginning of experimental operations is March 2000.

Q.3. In his opening remarks, Mr. Fawell also expressed concern about the introduction of tritium into the TFTR later this year. He noted that not only will this be done in a heavily populated area, raising safety and other environmental concerns, but it will also require expensive decontamination and decommissioning of the machine, and questioned whether the science we get will be worth this cost, or whether it would be more cost-effective to rely on JET, which has already used tritium.

A.3. The DOE has conducted a full environmental analysis of the TFTR D-T plan as required under the National Environmental Policy Act (NEPA). Consistent with the low hazard associated with this facility, an Environmental Assessment was performed and a Finding of No Significant Impact issued in January, 1992. In addition, public meetings were held to inform the local community of the D-T experiments, copies of the Environmental Assessment were provided to local governing bodies and distributed to libraries and public reading rooms. The public meetings were well attended. The public was given a presentation on the planned experiments and a tour of the facility which included the equipment which would be used for processing tritium. The response of the public and the public officials has been very supportive of the project and of the laboratory. The tritium equipment is now operational with small quantities of tritium.

The D-T experiments on TFTR were reviewed in full compliance with the National Environmental Policy Act (NEPA) and a comprehensive analysis of accident scenarios was performed. The basic analysis postulates an accident in which the double walled stainless steel storage bed containing tritium is breached and the cleanup system fails. This postulated accident would result in a dose at the site boundary of 140 mrem. In addition, the analysis also considers a more severe accident consisting of the postulated failure identified in the design basis accident, with the additional simultaneous failure of the HVAC system, producing a ground level release. This accident results in a dose at the site boundary of 390 mrem. The dose at the nearest office building is less than a third of the dose at the site boundary, and the dose at the nearest residence is only 3% of the dose at the site boundary. For comparison, the dose which residents experience in the Plainsboro Township due to ambient terrestrial radiation (including radon) is typically about 300 mrem annually in normal living quarters and 600 mrem in basement dwellings.

The TFTR D-T experiments will increase the activation and contamination of the equipment within the Test Cell. However, much of the equipment is already activated from deuterium operations. Thus, upon completion of the TFTR experiments using either deuterium or deuterium/tritium fuel, the device will have to be decontaminated and decommissioned and treated as low level radioactive waste. The difference between deuterium and deuterium-tritium operation is that the quantity of waste will increase after deuterium-tritium experiments by a factor of about two and the cost will be about a factor of two greater. We estimate that the cost of decontaminating and decommissioning TFTR after D-T experiments will be about $86M.

The D-T experiments on the Joint European Torus (JET) in 1991, while of significant interest, were very limited in scope. There were only two brief, moderate power D-T experiments. For comparison, the TFTR D-T program will include about 1000 experiments spanning a broad range of experimental conditions. The evaluation of possible collective alpha instabilities and the heating efficiency of alpha particles is needed in a timely fashion to support the design of ITER. For this TFTR can provide unique information. Due to the limited number of experiments, JET was not able to address the confinement of D-T plasmas, the effect of alpha particles on plasma stability and energy transport, the self-heating of the plasma by alpha particles, the accumulation of alpha ash, the effect of alpha particles on ICRF heating, and the confinement of the alpha particles, all of which will be studied extensively on TFTR. In the future, JET may be able to address some of these questions; however, JET does not have the same complement of diagnostics which TFTR has developed to address these physics issues in detail. Furthermore, the JET team is in the process of completing a major modification to their machine and the schedule for performing additional D-T experiments on JET is uncertain at this time. It should be noted that the research groups on TFTR and JET have been working and continue to work together on D-T physics issues. Several JET staff will participate in the TFTR D-T experiments and several of our staff members participated in the preliminary JET D-T experiments.

Q.4.a. The TPX is the latest in a series of proposed TFTR "follow-ons". First, there was the Compact Ignition Tokamak (CIT) and then the Burning Plasma Experiment (BPX). Please delineate the differences in these three devices, including performance parameters, expected contributions to the fusion program, and estimated costs.

A.4.a. CIT was an earlier version of BPX, with much the same mission, but more aggressive engineering and physics, and so lower cost and greater technical risk. The formal mission of BPX was "to determine the physics behavior of self-heated fusion plasmas and [to] demonstrate the production of substantial amounts of fusion power." This mission has been taken over as a major goal of the first phase of ITER.

The mission of TPX is "to develop the scientific basis for an economical, compact, and continuously operating tokamak fusion reactor." The advanced steady-state operating modes that are developed on TPX will lead to a substantially smaller and less expensive DEMO than could be based on results from ITER alone. Furthermore, a TPX-based DEMO will be able to run continuously, rather than in pulses, resulting in increased component lifetimes and higher reliability. Results from TPX will also be critical for optimizing the operations of ITER, and for guiding the planned upgrades to ITER subsystems.

	CIT	BPX	TPX
Major Radius	1.75 m	2.59 m	2.25 m
Minor Radius	0.55 m	0.80 m	0.5 m
Elongation	2.0	2.2	2.0
Magnetic Field	10.0 T	9 T	4 T
Plasma Current	9 MA	11.8 MA	2 MA
Pulse Flat-top	5 sec	7 sec	1000 sec
Fuel*	D-T	D-T	D-D (limited D-T)
External Heating	10 MW	20 MW	18 MW
Maximum Fusion Power	300 MW	500 MW	15 MW
Current Drive	0 MW	0 MW	18 MW
Cost	$740M FY89	$1.3B FY90	$530M FY93

Q.4.b. How much money has been spent to date on each of these three devices?

A.4.b. A total of $106 million was spent on the Compact Ignition Tokamak ($73 million from 1986 to 1990) and on the Burning Plasma Experiment ($33 million from 1991 to 1992) for design, and research and development on components. The funds spent in fiscal years 1992-93 on the Tokamak Physics Experiment conceptual design are projected to total $13 million.

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June 18, 1993

The Honorable Harris W. Fawell
Ranking Republican Member
Subcommittee on Energy
U. S. House of Representatives
Committee on Science, Space and Technology
Suite 2320 Rayburn House Office Building
Washington, DC 20515-6301

Dear Representative Fawell:

Attached are my answers to your questions concerning issues raised by Dr. Robert Hirsch. They reflect my own views as one who has been associated with fusion research since 1959.

My background in fusion includes working on fusion at General Atomic and being a Professor of Nuclear Engineering at the University of Wisconsin, work on fission at Exxon Nuclear Co. and now responsible for technology, including R & D, at Bechtel.

Also, I have known Dr. Hirsch since the late 1960s and have a high regard for his management capabilities. His current views of fusion are not new but his willingness to carry them to the extent he has are surprising and worrisome. Obviously, he feels very strongly about the issues.

I hope these comments and answers are useful.

Sincerely,

H K Forsen

Harold K. Forsen
Senior Vice President and Manager
Bechtel Technology Group

HKF:mc
Attachments

cc: Representative Marilyn Lloyd

Bechtel Corporation

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation

June 17, 1993

Question 1.a

Please comment on Dr. Hirsch's observation that deuterium-tritium (DT) tokamak and laser-fusion reactors as currently envisioned will be extremely complex, highly radioactive, likely to be highly regulated, and costly.

Answer 1.a: Fusion reactors, both magnetic fusion and inertial fusion, are at a state of development that one cannot really determine what the commercial embodiment will look like. Any utility operator viewing a large fusion experiment today would find themselves overwhelmed by the peripheral instruments, measuring and diagnostic apparatus, heating and remote handling equipment and so on. Power reactors will not have all of this "confusing" complexity. This will be independent of whatever fuel cycle is used.

As to radioactivity, fusion DT, DD, DHe^3 or whatever we can make work, will have radioactivity as long as deuterium is used because all deuterium burning reactors produce some neutrons. Thus, we are not arguing whether it is radioactive, but how much. Therefore, there are health and safety issues and they will be regulated. Whether they are costly is a subject no one today can answer because the question is costly compared to what. There is less radiation in a DT ractor than in a fission reactor, they will be safer and have a better contained fuel cycle, they can be more efficient because of possible higher teperature safety and so on.

Question 1.b

Please comment on Dr. Hirsch's observation that even if DT or laster fusion reactors had the same capital costs as a fission reactor - an enormous challenge - fusion reactors would lose out to advanced fission reactors, which are a reliable, known quantity.

Answer 1b: Fusion reactors will only lose out to advanced fission reactors if the public believes they are not safer, or if they are not competitive in price. Today, we cannot estimate the real cost of fission because we have no real data. Fission cost ranges from $600 to $3,000/KWe have been speculated or supported by historical data. Fusion reactors have also been speculated to cost in this range but until one has been designed, licenced, built and operated, we can only estimate.

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation

June 17, 1993

Answer 1.b - cont'd.

Assuming Dr. Hirsch is speaking of Advanced Liquid Metal Reactors (ALMRs) or High Temperature Gas Cooled Reactors (HTGRS) as advanced fission reactors that are a "reliable, known quantity" - he must be kidding. The only ALMRs are French reactors that have had nothing but problems, and none are currently operating. They employ a fuel cycle that, today, the U. S. public would not accept and the current U. S. program is projected to be stopped. HTGRs of the advanced variety have not been built and have a fuel cycle totally different from that of LWRs operating today. While there certainly is more experience with "advanced fission reactors", they are by no stretch of the imagination reliable or known and none are commercial.

Question 1.c

Please comment on Dr. Hirsch's observation that none of the very few fusion-knowledgeable utility people he had spoken with believes that tokamak or laser fusion reactors, as currently envisioned, would be acceptable to the electric utilities.

Answer 1.c: Here I believe the issue relates back to my comments on experiments in 1a. Clearly these experiments appear strange and are complicated to operate. On the other hand, if these same utility people had viewed fission reactors during their experimental days, they may have voiced the same concerns. By the same token, if one were to compare gas turbine electric generators, those being bought by utilities today, they are simple by comparison to a modern oil or coal fired fossil plant. The point being some things are more complicated than others. It does not mean one is better, it means they are different. Costs, safety, environmental issues and fuel supply will dictate operations when fusion becomes available. Operator training will be important but will present no real issue as to whether utilities buy them or not.

Dr. Hirsch cannot give us any alternative to the tokamak that would be more attractive to the utilities and guarantee it will perform as well.

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation — June 17, 1993

Question 1.d

Please comment on Dr. Hirsch's observation that there are some enormous materials prob lems related to DT fusion. There are no qualified materials today for DT fusion reactors. In the absence of development of a low activity material - a very costly and time consuming undertaking - you will have to effectively rebuild your fusion reactor every 5-10 years and dispose of many times the amount of radioactivity that would come from a fission reactor of the same power level.

Answer 1d: There are materials that can be qualified for fusion reactors today. We hope that even better materials can be found for the future. If the fusion reactor were to be built from today's materials, say HT-9, the afterheat from its activation would be over a thousand times less than a fission reactor after one year. Moreover, every year one-third of the fission reactor's core must be replaced. The fission fragments and transuranics contained in this replaced core is hotter than any equivalent volume or weight in a fusion reactor.

The comment of disposing of many times the amount of radioactivity from a fusion reactor compared to a fission reactor is just wrong. What you may have in a fusion reactor is a greater volume of low level waste. Experts[1] have calculated the waste disposal rating of an LMFBR (Liquid Matal Fast Breeder Reactor - same as a ALMR) is 1200 times worse than a fusion reactor. Should the advanced silicon based structural materials be developed, the unfavorable waste disposal rating of ALMR over fusion goes to 7,500,000.

1) J. P. Holdren, "Safety and Environmental Aspects of Fusion Energy" Annual Review of Energy and Environment. 16:235-258, (92992)

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation

June 17, 1993

Question 1.e

Please comment on Dr. Hirsch's observation that if tokamak reactors, as currently envisioned, aren't acceptable, can ITER be possibly justified?

Answer 1e: ITER is the experiment that will prove the final physics issues of fusion development while giving us a good handle on many of the technology issues. Answers to question 1a, 1c and 1d help to put into perspective that the DT tokamak fusion approach is the most advanced and attractive that nature has to offer. Dr. Hirsch's premise that they are not acceptable is speculative and without foundation .

Perhaps here one should digress and comment on alternate aproaches to the tokamak for magnetic fusion. From the first days of fusion research, everyone had their favorate confinement scheme. Studies were carried out on pinches, stellarators, rf systems, electrostatic systems, mirrors, cusps, beam injectors and many more. All of these had one or more experiments and several grew to large scale because the data were encouraging. These included mirrors, stellarators and one or two others. For many years though, confinement was always worse than what we could calculate using classical models. The Russian tokamak found a way through this period of so-called "Bohm diffusion" confinement to produce a system that appeared to scale. Many many tokamaks have been operated and scaling continued to be favorable. In fact most large tokamak experiments today perform better than early theory would predict. The ITER is designed more conservatively than some concepts for power reactors. Here the issue is in understanding just how scaling and theory are tied together in plasma physics.

For the fusion program to make the great strides that it has since the evolution of the tokamak, for all the confinement approaches mentioned above, budgets over ten times greater than those appropriated would be required. Congress has pushed for progress, tokamaks have provided progress (over factors of 10^6 in confinement in less than 30 years) and one cannot have it both ways. No other confinement approach has ever paralleled these exciting results in approaching the conditions necessary to ignite a fusion reactor.

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation **June 17, 1993**

Question 1.f

Please comment on Dr. Hirsch's observation that if you build ITER, it will become the flagship of fusin and will likely eliminate the chance of serious funding for alternate concepts.

Answer 1.f: The last question addresses this in part. Tokamaks are the most attractive confinement approach we understand and, yes, the ITER will become the international flagship for fusion . Every country in the world that undertakes magnetic fusion research is betting most of its resources on the tokamak and consequently, ITER is a key element. They, like the U. S., fund alternate concepts at some low level reflective of the comparative progress these alternates have made. There is no really outstanding, deserving approach that does not receive some funding as determined by the technical community's peer review in the respective countries.

Question 1.g:

Please comment on Dr. Hirsch's observation that if what ITER represents is seriously considered in public debate, there is high probability that ITER will not be supported and the fusion program could collapse.

Answer 1.g: The public debate in scientific circles has taken place as suggested in 1.f and the community has recommended we proceed with ITER. Should politics enter the debate as Dr. Hirsch would appear to advocate, fusion progress would be slowed, we could revert to a university level academic approach, and the public would never have the chance to evaluate the economic and safety attributes of a fusion demonstration.

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation — June 17, 1993

Question 1.h

Please comment on Dr. Hirsch's recommendation that scale-up of alternate R&D concepts proceed as fast as possible.

Answer 1.h: There are no outstanding, deserving approaches which scale as attractive as the tokamak. Consequently, taking alternatives which are less attractive than the tokamak in the parameters required for ignition by factors of 10^3 to 10^4 and spending 10^{-2} to 10^{-3} of the cost of ITER (i.e. 10 times more per favorable scaling factor) is folly since there are at least 10 different approaches that their advocates propose and none of them are ready for an ITER scale demonstration.

Question 1.i:

Please comment on Dr. Hirsch's recommendation that tokamak or laser fusion not be stopped, but cut back and reoriented in more acceptable direction.

Answer 1.i: Dr. Hirsch's question 1.h and others are the same as this one. He must provide specific recommendation that can be debated rather than generalities.

Question 1.j:

Please comment on Dr. Hirsch's recommendation that we get off the DT fuel cycle to avoid frequent reactor reconstruction, large quantity radwaste disposal. and expensive materials development.

Answer 1.j: DT fuel it the most abundant and easiest fuel to burn in fusion. (The T or tritium comes from fissioning lithium within the reactor blanket. Thus, the real fuel is deuterium and lithiuml). Alternate fuels pose more difficult confinement and ignition issues, have similar radioactive contamination problems, and are not readily available at attractive prices. See also question 1.a

Questions by Representative Harris W. Fawell, Ranking Republican Member Subcommittee on Energy and answers provided by Dr. Harold K. Forsen, Senior Vice President, Bechtel Corporation

June 17, 1993

Question 2:

What are the features of tokamak reactors that you believe would be attractive to a utility or to an independent power producer (IPP)?

Answer 2: The tokamak reactor embodies all the benefits of fusion in that they are safe; environmentally more attractive than fission but like fission have no CO_2, NOx or SOx pollution problems; and have a fuel cycle that is available and relatively benign.

Further are the availability of subsystem suppliers, such as magnets, vacuum systems, control systems, heat exchange suppliers and turbine suppliers. And system integrators prepared to step up in their role to demonstrate fusion power systems.

There are no nuclear engineering issues such as reactivity control, nuclear runaway concerns, actinide production and volatile fission gasses with long half lives which occur in fission systems.

These issues should help assure licensability, available siting and public acceptance. It is also possible to guarantee better the capital investment against explosion or uncontrolled contamination.

Question 3.:

How much of its own funding is Bechtel investing in fusion energy?

Answer 3: Bechtel has no DOE contracts in magnetic fusion energy. We invest in people's time and travel to review, support, testify and understand fusion to the extent of about $100,000 per year as a very rough figure.

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June 22, 1993
566-93-RTW

The Honorable Harris W. Fawell
Ranking Republican Member
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives
H2-390 Ford House Office Building
Washington, DC 20515

Attn: Dr. Harlan A. Watson

Dear Congressman Fawell,

This letter is in response to your questions of June 11, 1993. My testimony to the Subcommittee did not deal with either tokamaks or laser-fusion reactors; however, I have personally worked on a variety of approaches to magnetic fusion, including tokamaks, and I now have responsibility for both magnetic and inertial fusion research at Lawrence Berkeley Laboratory. Moreover I recently chaired the Fusion Energy Advisory Committee's panel on materials, so I am very familiar with the materials challenges associated with DT fusion.

None of Dr. Hirsch's arguments is new. The issues he raises regarding DT tokamaks have been thoroughly discussed and argued by fusion researchers worldwide for many years. Many, perhaps even most, fusion researchers agree that DT tokamaks "as currently envisioned" may not be the ultimate solution to commercial fusion power production; however, tokamaks currently perform better than any other magnetic fusion devices and DT is easier to ignite than any other fusion fuel. Therefore, DT tokamaks are the quickest, surest path to the scientific demonstration of magnetic fusion. (After all, magnetic fusion has not yet been proven experimentally.) In the world-wide fusion community there is a consensus that the research path that leads through, though perhaps not ultimately to, DT tokamaks is the appropriate path. The number of papers on alternate magnetic concepts presented at international conferences has declined dramatically during the last decade. Dr. Hirsch represents the minority opinion that we should now move aggressively beyond the DT tokamak step. I disagree with Dr. Hirsch.

I find Dr. Hirsch's comments regarding inertial fusion incomplete, in that he consistently refers to laser fusion rather than inertial fusion. Like tokamaks, glass lasers are the fastest path to a laboratory demonstration of inertial fusion. (The scientific feasibility of inertial fusion on a large scale, because it has been demonstrated with nuclear weapons, is not in doubt.) But lasers are not particularly well suited to power production. As I noted in my testimony, nearly all high-level review committees have identified heavy-ion accelerators as the most promising approach to inertial fusion power production. There is a consensus that inertial fusion research should include lasers for near-term laboratory-scale scientific and military applications and accelerator research for power production.

In summary, Dr. Hirsch raises important, but not new, issues. His proposed research path for magnetic fusion is a minority view. For inertial fusion, he is correct that lasers are not particularly suited for power production. In fact, the important question for inertial fusion as a power source is the feasibility of heavy-ion accelerators. I will therefore take the liberty of responding to the questions about laser fusion with comments about heavy-ion fusion.

1a) Please comment on Dr. Hirsch's observation that deuterium-tritium (DT) tokamak and laser-fusion reactors as currently envisioned will be extremely complex, highly radioactive, likely to be highly regulated, and costly.

Existing accelerators for high energy and nuclear physics are comparable in size and complexity to the accelerators that will be needed for fusion. Many of these accelerators have demonstrated reliability that exceeds the requirements for power production. These machines are typically run and maintained by technicians, not Ph.D. scientists. Thus, although these accelerators are complex, they are not too complex. The reactor and target factory of an inertial fusion power plant add some complexity, but these components will likely be less complex than the accelerator.

In an inertial fusion reactor it is possible to protect the first structural wall with a neutronically thick fluid layer of low-activation material. Even with DT fuel the reactor does not become highly radioactive. Calculations show that a properly designed heavy-ion fusion reactor can qualify for disposal by shallow burial under current regulations.

Studies worldwide predict acceptable cost (about six cents per kilowatt hour) for heavy-ion fusion; however, these studies are based on assumptions that must be checked by experiments.

1b) Please comment on Dr. Hirsch's observation that even if DT or laser fusion reactors had the same capital costs as a fission reactor—an enormous challenge—fusion reactors would lose out to advanced fission reactors, which are a reliable, known quantity.

Dr. Hirsch assumes that fusion reactors will not be reliable, known quantities. I believe that they can be reliable, known quantities—that's the goal of the fusion program. If the two technologies are comparable in cost and reliability, fusion is clearly the technology of choice because it produces much less radioactivity.

1c) Please comment on Dr. Hirsch's observation that none of the very few fusion-knowledgeable utility people he had spoken with believes that tokamak or laser fusion reactors, as currently envisioned, would be acceptable to the electric utilities.

I agree with Dr. Hirsch that tokamaks and laser fusion reactors "as currently envisioned" are not attractive to utilities. On the other hand, it is premature to believe that the reactors we will someday build are the reactors that we envision today.

1d) Please comment on Dr. Hirsch's observation that there are some enormous materials problems related to DT fusion. There are no qualified materials today for DT fusion reactors. In the absence of development of a low activity material—a very costly and time consuming undertaking—you will have to effectively rebuild your fusion reactor every 5-10 years and dispose of many times the amount of radioactivity that would come from a fission reactor of the same power level.

There are difficult materials challenges for DT magnetic fusion; however, calculations show that inertial fusion reactors, with fluid wall protection, can use existing, commercially available alloys. Furthermore, the reactor walls are calculated to last the life of the plant and to produce far less radioactivity that fission plants or fusion plants without fluid wall protection.

Ie-Ii) Please comment on Dr. Hirsch's observation that if tokamak reactors, as currently envisioned, aren't acceptable, can ITER be possibly justified and that if you build ITER, it will become the flagship of fusion and will likely eliminate the chance of serious funding for alternate concepts. Please comment on Dr. Hirsch's observation that if what ITER represents is seriously considered in public debate, there is high probability that ITER will not be supported and the fusion program could collapse and that scale-up of alternate R&D concepts proceed as fast as possible. Please comment on Dr. Hirsch's recommendation that tokamak or laser fusion not be stopped, but cut back and reoriented in more acceptable directions.

In the early days of the fusion program many alternate concepts were tried—and failed. As our understanding of magnetic confinement of plasmas improved, it became clear that "bench-top" experiments could not achieve the necessary conditions of temperature, density, and confinement time. Indeed, with the larger (and more costly) facilities it has been possible to demonstrate conditions close to scientific breakeven—close enough to give confidence that ITER can demonstrate ignition and self-sustained "burn" of a plasma. That will be a major step forward for magnetic fusion.

In my opinion, magnetic fusion suffers credibility in the public's eye because breakeven has often been promised, but not achieved. Alternate concepts will not be able to demonstrate breakeven in a short time frame. The best chance for gaining adequate support for the fusion program, so that alternate concepts and accelerated materials development can be funded, will be a demonstration of breakeven, which ITER can provide.

A successful ITER will rally the support needed to design and build magnetic fusion reactors that take full advantage of the promises of fusion—safe, environmentally benign energy from a near-limitless fuel supply.

Ij) Please comment on Dr. Hirsch's recommendation that we get off the DT fuel cycle to avoid frequent reactor reconstruction, large quantity radwaste disposal, and expensive materials development.

With fluid wall protection in inertial fusion reactors, frequent reactor reconstruction is not necessary. Fluid wall protection greatly diminishes the radwaste disposal problem and existing, commercial alloys can be used for reactor construction. There are important issues that must be addressed, but there is a plausible path to an attractive inertial fusion reactor with fluid wall protection.

2) What are the relative advantages and disadvantages of inertial fusion and magnetic fusion?

Dr. Roger Bangerter of our laboratory recently wrote a brief comparison of magnetic and inertial fusion. In response to this question, I am enclosing a copy of Dr. Bangerter's comparison.

3) What is your estimated cost of the next generation accelerator required to achieve inertial fusion energy?

The next accelerator proposed for heavy-ion fusion research is ILSE (Induction Linac Systems Experiments). ILSE will not produce fusion energy. Although many of the requirements for power production have been demonstrated at existing accelerators some have not. ILSE, with a total project cost of $53.3M, will address the remaining accelerator issues and provide the basis for designing accelerators for fusion.

Current cost estimates for full-scale accelerators range from about 0.5 to 2 billion dollars. The cost estimates are uncertain because accelerator technology is developing rapidly. Advances in superconductivity, magnet technology, insulators, ferromagnetic materials, solid-state electronic devices, and precision fabrication techniques are expected to have a favorable impact on costs.

4) What are the advantages of heavy-ion fusion relative to laser or light-ion inertial fusion?

All proposed laser systems have inadequate or marginal efficiency for power production. Moreover there are no truly credible schemes for protecting the lenses that are used to focus the beams onto the targets. Light-ion accelerators may have adequate efficiency, but there are serious questions about beam quality (focusability) and long-term durability. Heavy-ion accelerators appear capable of high efficiency, long life, good reliability, and high pulse repetition rate. The beam quality demonstrated in small-scale experiments is excellent.

Sincerely yours,

K Berkner

Klaus H. Berkner
Associate Laboratory Director
for Operations

Attachment

APPENDIX II

EPRI
Electric Power
Research Institute

Keywords:
Electric power
Exploratory research
Fusion reactors
Nuclear fusion
Plasma technology
Power system engineering

EPRI TR-101649
Final Report
November 1992

Report of the 1992 Fusion Panel

Prepared by
Electric Power Research Institute

STATEMENT FOR THE RECORD

OF DR. ROBERT L. HIRSCH

VICE PRESIDENT - WASHINGTON OFFICE

ELECTRIC POWER RESEARCH INSTITUTE

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

MAY 5, 1993

This better path or paths to desirable fusion power will likely involve lower cost steps than ITER sized tokamaks. This is because a competitively priced fusion power system will inherently be smaller in size, and, therefore, less expensive. But fusion research and development is likely to be costly no matter what, so that continued international collaboration will be highly desirable.

In order for fusion research to be successful, marketplace realities must have an essential role in fusion program directions and decisions. Electric utilities represent the marketplace in today's world. Unfortunately, utilities have never been involved in fusion research in a serious role. Both Dr. Davies and I recognized this shortcoming roughly a year ago and we have been taking steps to close that gap.

To begin to formulate some utility views on fusion, last year EPRI created a panel composed of some of its executives to consider the practical aspects of fusion reactors. Our report, dated November 1992, reached a number of conclusions, some of the more important of which are as follows:

- The federal fusion research program represents an important national investment.

- In the relative near term producing deuterium-tritium fusion power in the 10-20 megawatt-thermal range in the Princeton TFTR is an important program milestone and should continue to be a high priority.

- Program diversity beyond tokamaks is important. In diversifying its fusion program, the DOE should give special consideration to concepts that are less complex and power plant designs based on fuel cycles other than deuterium-tritium.

- The eventual needs of the marketplace should become a critical element in fusion program planning and decision-making.

IEEE **UNITED STATES ACTIVITIES**

Promoting Career and Technology Policy Interests of Electrical, Electronics & Computer Engineers

STATEMENT

by the

ENERGY POLICY COMMITTEE
INSTITUTE OF ELECTRICAL AND ELECTRONICS
ENGINEERS - UNITED STATES ACTIVITIES

to the

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE, SPACE
AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

on the

DEPARTMENT OF ENERGY'S
FUSION ENERGY PROGRAM

May 14, 1993

The Energy Policy Committee of the Institute of Electrical and Electronics Engineers - United States Activities (IEEE-USA) is pleased to submit its views on the Department of Energy's FY 1994 budget request for fusion energy.

The Energy Policy Committee believes an adequate energy supply is vital to the economic growth and security of the nation and the world and to the nation's international competitiveness. The nation's electrical supply system must be reliable and continuous and must have minimal impact on the environment and on global climate change. Extensive research and development will be required to improve present energy sources and to develop new ones that have reduced environmental impact and can provide increased energy security. Research aimed at timely demonstration of fusion as a viable power source for base load electrical power generation will insure that fusion can become an important element in a balanced portfolio of energy technologies in the future.

DOE'S MAGNETIC FUSION ENERGY PROGRAM PROGRESS AND PROSPECTS

The production of an average of 1 megawatt (peak 1.7 MW) of fusion power for a duration of two seconds by using a deuterium and tritium mixture in the Joint European Torus (JET) in November, 1991 represented a milestone in the fusion program. This was the first use of a significant amount of the more reactive tritium fuel and the first production of significant fusion power.

The production of 10-20 megawatts of fusion power with a deuterium-tritium fuel mixture in the TFTR at Princeton in FY 1993-1994 will be the next step in the progression toward understanding the physics of fusion plasmas and demonstrating fusion power production in the laboratory.

Another advance in MFE is the observation that plasma confinement and stability depend critically on the spatial distribution of the plasma current, the plasma shape, and the radial electric field. These properties are controllable and provide directions for improving tokamak performance. The achieved factor of three containment enhancement is good enough for a breakeven reactor.

In 1991, the SEAB Task Force on Energy Research Priorities recommended that the Burning Plasma Experiment (BPX) not be constructed due to budgetary constraints; cancellation of BPX was explicitly not due to the quality of the proposed program. During 1992, the Fusion Energy Advisory Committee (FEAC) engaged in an intense process of program review and development, targeted at the proposal of a ~$400M (FY 1992 dollars) device that would be affordable. The magnetic fusion community examined a spectrum of next-device missions and determined that study of steady-state advanced tokamak issues was the appropriate mission for a $400M (FY 1992) device. The FEAC recommended this mission to the SEAB Task Force, which in turn recommended the construction of the Tokamak Physics Experiment (TPX) to DOE. President Clinton has listed TPX as an element of his "economics investment package."

DOE'S INERTIAL CONFINEMENT FUSION PROGRAM PROGRESS AND PROSPECTS

In inertial confinement fusion, steady progress is being made in reaching higher fuel temperatures and controlling the instabilities that limit achievable compressions. In the past year, technical achievements in the ICF program have included advances by Lawrence Livermore National Laboratory and Los Alamos National Laboratory in modeling laser-target interactions for pulse-shaped radiatively-driven targets on NOVA, progress on construction of a direct-drive KrF laser facility at the Naval Research Laboratory, and development of plans to upgrade the OMEGA glass laser at the University of Rochester. In addition, international collaboration in experiments on PBFA II (at Sandia National Laboratories),